ANNUAL REPORT OF THE BOARD OF REGENTS OF

THE SMITHSONIAN INSTITUTION

SHOWING THE

OPERATIONS, EXPENDITURES, AND CONDITION OF THE INSTITUTION FOR THE YEAR ENDING JUNE 30

1928

(Publication 2981)

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1929

ADDITIONAL COPIES

OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
$2.00 PER COPY (CLOTH)

LETTER

FROM THE

SECRETARY OF THE SMITHSONIAN INSTITUTION

SUBMITTING

THE ANNUAL REPORT OF THE BOARD OF REGENTS OF THE INSTITUTION FOR THE YEAR ENDED JUNE 30, 1928

SMITHSONIAN INSTITUTION,
Washington, November 26, 1928.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ended June 30, 1928. I have the honor to be,

Very respectfully, your obedient servant,

C. G. ABBOT, *Secretary.*

CONTENTS

General Appendix

LIST OF PLATES

ANNUAL REPORT OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1928

SUBJECTS

1. Annual report of the secretary, giving an account of the operations and condition of the Institution for the year ending June 30, 1928, with statistics of exchanges, etc.

2. Report of the executive committee of the Board of Regents, exhibiting the financial affairs of the Institution, including a statement of the Smithsonian fund, and receipts and expenditures for the year ending June 30, 1928.

3. Proceedings of the Board of Regents for the fiscal year ending June 30, 1928.

4. General appendix, comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1928.

THE SMITHSONIAN INSTITUTION

June 30, 1928

Presiding officer ex officio.—CALVIN COOLIDGE, President of the United States.
Chancellor.—WILLIAM HOWARD TAFT, Chief Justice of the United States.
Members of the Institution:
CALVIN COOLIDGE, President of the United States.
CHARLES G. DAWES, Vice President of the United States.
WILLIAM HOWARD TAFT, Chief Justice of the United States.
FRANK B. KELLOGG, Secretary of State.
ANDREW W. MELLON, Secretary of the Treasury.
DWIGHT FILLEY DAVIS, Secretary of War.
JOHN G. SARGENT, Attorney General.
HARRY S. NEW, Postmaster General.
CURTIS D. WILBUR, Secretary of the Navy.
HUBERT WORK, Secretary of the Interior.
WILLIAM M. JARDINE, Secretary of Agriculture.
HERBERT CLARK HOOVER, Secretary of Commerce.
JAMES JOHN DAVIS, Secretary of Labor.
Regents of the Institution:
WILLIAM HOWARD TAFT, Chief Justice of the United States, Chancellor.
CHARLES G. DAWES, Vice President of the United States.
REED SMOOT, Member of the Senate.
JOSEPH T. ROBINSON, Member of the Senate.
CLAUDE A. SWANSON, Member of the Senate.
ALBERT JOHNSON, Member of the House of Representatives.
R. WALTON MOORE, Member of the House of Representatives.
WALTER H. NEWTON, Member of the House of Representatives.
ROBERT S. BROOKINGS, citizen of Missouri.
IRWIN B. LAUGHLIN, citizen of Pennsylvania.
FREDERIC A. DELANO, citizen of Washington, D. C.
DWIGHT W. MORROW, citizen of New Jersey.
CHARLES EVANS HUGHES, citizen of New York.
JOHN C. MERRIAM, citizen of Washington, D. C.
Executive committee.—FREDERIC A. DELANO, R. WALTON MOORE, JOHN C. MERRIAM.
Secretary.—CHARLES G. ABBOT.
Assistant Secretary.—ALEXANDER WETMORE.
Chief clerk.—HARRY W. DORSEY.
Accounting and disbursing agent.—NICHOLAS W. DORSEY.
Editor.—WEBSTER P. TRUE.
Librarian.—WILLIAM L. CORBIN.
Appointment clerk.—JAMES G. TRAYLOR.
Property clerk.—JAMES H. HILL.

NATIONAL MUSEUM

Assistant Secretary (in charge).—Alexander Wetmore.
Administrative assistant to the Secretary.—William de C. Ravenel.
Head curators.—Walter Hough, Leonhard Stejneger, George P. Merrill.
Curators.—Paul Bartsch, Ray S. Bassler, Theodore T. Belote, Austin H. Clark, Frank W. Clarke, Frederick V. Coville, Charles W. Gilmore, Walter Hough, Leland O. Howard, Aleš Hrdlička, Neil M. Judd, Herbert W. Krieger, Frederick L. Lewton, George P. Merrill, Gerrit S. Miller, Jr., Carl W. Mitman, Robert Ridgway, Waldo L. Schmitt, Leonhard Stejneger.
Associate curators.—John M. Aldrich, Ellsworth P. Killip, William R. Maxon, Charles E. Resser, Charles W. Richmond, David White.
Chief of correspondence and documents.—Herbert S. Bryant.
Disbursing agent.—Nicholas W. Dorsey.
Superintendent of buildings and labor.—James S. Goldsmith.
Editor.—Marcus Benjamin.
Assistant Librarian.—Isabel L. Towner.
Photographer.—Arthur J. Olmsted.
Property clerk.—William A. Knowles.
Engineer.—Clayton R. Denmark.

NATIONAL GALLERY OF ART

Director.—William H. Holmes.

FREER GALLERY OF ART

Curator.—John Ellerton Lodge.
Associate curator.—Carl Whiting Bishop.
Assistant curator.—Grace Dunham Guest.
Associate.—Katharine Nash Rhoades.
Superintendent.—John Bundy.

BUREAU OF AMERICAN ETHNOLOGY

Ethnologists.—John P. Harrington, John N. B. Hewitt, Francis La Flesche, Truman Michelson, John R. Swanton.
Archeologist—Frank H. H. Roberts, Jr.
Editor.—Stanley Searles.
Librarian.—Ella Leary.
Illustrator.—De Lancey Gill.

INTERNATIONAL EXCHANGES

Secretary (in charge).—Charles G. Abbot.
Chief clerk.—Coates W. Shoemaker.

NATIONAL ZOOLOGICAL PARK

Director.—William M. Mann.
Assistant director.—Arthur B. Baker.

ASTROPHYSICAL OBSERVATORY

Director.—Charles G. Abbot.
Research Assistant.—Frederick E. Fowle, Jr.
Research assistant.—Loyal B. Aldrich.

REGIONAL BUREAU FOR THE UNITED STATES, INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE

Assistant in charge.—Leonard C. G

REPORT

OF THE

SECRETARY OF THE SMITHSONIAN INSTITUTION

C. G. Abbot

FOR THE YEAR ENDING JUNE 30, 1928

To the Board of Regents of the Smithsonian Institution:

Gentlemen: I have the honor to submit herewith my report showing the activities and condition of the Smithsonian Institution and the Government bureaus under its administrative charge during the fiscal year ended June 30, 1928. The first 28 pages contain a summary account of the affairs of the Institution. Appendixes 1 to 10 give more detailed reports of the operations of the United States National Museum, the National Gallery of Art, the Freer Gallery of Art, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, the United States Regional Bureau of the International Catalogue of Scientific Literature, the Smithsonian library, and of the publications issued under the direction of the Institution; and Appendix 11 contains a list of subscribers up to October 15, 1928, to the James Smithson Memorial Edition of the Smithsonian Scientific Series.

THE SMITHSONIAN INSTITUTION

THE ESTABLISHMENT

The Smithsonian Institution was created by act of Congress in 1846, according to the terms of the will of James Smithson, of England, who, in 1826, bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was without authority to administer the trust directly, and therefore constituted an "establishment" whose statutory members are "the President, the Vice President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS

The affairs of the Institution are administered by a Board of Regents whose membership consists of "the Vice President, the Chief Justice, three Members of the Senate, and three Members of the House of Representatives, together with six other persons other than Members of Congress, two of whom shall be resident in the city of Washington, and the other four shall be inhabitants of some State, but no two of them of the same State." One of the Regents is elected chancellor by the board; in the past the selection has fallen upon the Vice President or the Chief Justice; and a suitable person is chosen by the Regents as Secretary of the Institution, who is also secretary of the Board of Regents, and the executive officer directly in charge of the Institution's activities.

The following changes occurred in the personnel of the board during the year: Senator Woodbridge N. Ferris died on March 23, 1928, and Senator Claude A. Swanson was appointed to succeed him on March 28, 1928. The board also lost by death the Hon. Henry White and Mr. Charles F. Choate, jr., and their places were filled by the appointment of the Hon. Charles Evans Hughes on December 21, 1927, and Dr. John C. Merriam on December 21, 1927.

The roll of the Regents at the close of the fiscal year was as follows: William H. Taft, Chief Justice of the United States, chancellor; Charles G. Dawes, Vice President of the United States; members from the Senate, Reed Smoot, Joseph T. Robinson, Claude A. Swanson; members from the House of Representatives, Albert Johnson, R. Walton Moore, Walter H. Newton; citizen members, Robert S. Brookings, Missouri; Irwin B. Laughlin, Pennsylvania; Frederic A. Delano, Washington, D. C.; Dwight W. Morrow, New Jersey; Charles Evans Hughes, New York; and John C. Merriam, Washington, D. C.

GENERAL CONSIDERATIONS

Elected on January 10, 1928, to be Secretary of the Smithsonian Institution, it became my duty to study the nature of the Institution, its sources of strength, and the most effective ways in which it may advance the mission of its founder, James Smithson, "for the increase and diffusion of knowledge among men."

To the casual observer it may appear that the most important function of the Smithsonian is the administration of the public Museum, art galleries, and Zoological Park confided to its direction. In these days of easy travel the number of those who walk through the National Museum, the Freer Gallery, and the Zoological Park reaches several millions each year. The educational value is great, though doubtless the influence exercised on the minds of many visitors is

rather of the nature of the agreeable spending of a few hours. It would be interesting to determine the geographical dispersion of the benefits from these exhibition features of the Smithsonian. Almost certainly, however, it would be found that chiefly the District of Columbia, Maryland, and Virginia, after them the Eastern States, and then, with rapidly growing sparseness of distribution, the more distant States and foreign countries partake of these benefits.

Contrast with this comparatively local influence the wider reach of the International Exchange Service, as associated with the publications of the Institution. Its first Secretary, Joseph Henry, perceiving the isolation of science in the America of 1850, created, as one of the first Smithsonian activities, a system of exchange of its publications, receiving in return those of the learned institutions of the Old World. Having established at strategic points in other countries many agencies for such exchange, he offered the use of the system freely to the learned institutions of the United States. Along with this new departure he also inaugurated that of the free distribution of numerous copies of Smithsonian publications to selected libraries all over this country and the world. From such exchanges came to the Institution that still-continuing steady stream of foreign and domestic scientific literature which largely makes up the Smithsonian deposit of some half million volumes in the Library of Congress, and the eight extensive libraries retained in the Institution itself. This Government, and foreign governments as well, have appreciated the merit of this world-wide interchange of ideas which Secretary Henry inaugurated, and by treaty have built on the Smithsonian's foundation the present International Exchange System.[1]

Here, then, is a permanent and world-wide activity, originally Smithsonian, promoting international good will at the same time that it gives a powerful stimulus to the promotion of science and to the initiation of good intellectual activities, wherever instituted. As evidences of its effectiveness for good will, let me only say that owing to it one finds the golden torch symbolic of the Smithsonian Institution shown with pride on the shelves of libraries all over the world; that it was through the exchanges that Belgian libraries recovered many sets of American and other publications after the Great War; and that Japanese libraries were rehabilitated after the disastrous earthquake.

In the west hall of the Smithsonian Building the visitor sees a column of books four square, 23 feet high, with this legend:

Smithsonian Institution publications only. No duplicates. One thousand five hundred copies of each distributed world-wide free.

In the last 50 years scarcely one scientific textbook has appeared which does not owe something to these publications.

---

[1] See report on p. 85.

They include not only technical descriptions of original research of specialists in many lines, but also timely, readable, yet authoritative accounts of many of the principal scientific developments of our time.

Not less world-wide in distribution and value than its activities for its diffusion are the Smithsonian's accomplishments for the increase of knowledge. In consideration of our present status let me draw attention to several unique advantages which render the Institution responsible for the cultivation of research. The National Museum, the Bureau of American Ethnology, the Freer collections, and, to a lesser extent, the Zoological Park, contain much of the basis on which research in natural history and ethnology must forever depend. What the public sees in the National Museum is not a tithe of its national wealth. The study collections which crowd the laboratories and corridors of the Natural History Building and Smithsonian Building represent the fauna, flora, geology, paleontology, and ethnology of our country and other regions. They contain thousands of type specimens, to which the scientific world looks as standards. They include thousands of series exhibiting the modifying influences of environment. They contain specimens which were collected many years ago, and of which the march of progress has now forever cut off the possibility of duplication.

Extensive researches of scientific value, and not infrequently of immediate practical utility, have already been based on this material. But one who has any conception at all of the opportunity can not but be impressed with Smithsonian responsibility. Not only must the task of collecting and preserving specimens of the fauna, flora, ethnological, and paleontological material at present available be diligently pushed forward, lest they be forever lost, but the intensive study of the collections must also be a major task, lest the lessons they might teach should be lost to our generation.

Joseph Henry was not only one of America's foremost men of vision and of action, but a great physicist. In his time the physical sciences, physics, chemistry, mathematics, astronomy, meteorology were ardently cultivated by the Smithsonian. Yet for many years past the Institution's principal contribution to research in such lines has been in its administration of the Astrophysical Observatory. There has been trained there a corps of investigators whose expert knowledge of the conditions governing the flow of radiation and of heat is a valuable asset, and a large collection of special apparatus lies in their care. During the years that they have devoted to studies of solar and terrestrial radiation there has at length developed a public demand for progress in our knowledge of the relations of radiation to climate, to the growth of plants, and to the health of human

beings. I feel that to march resolutely into these fields of investigation, which involve not only physics but chemistry, mathematics, meteorology, and astronomy, is a policy dictated to the Smithsonian not only by its possession of these assets of experience and apparatus but by the traditions of its early history, by the interests of its founder, James Smithson, who was a research chemist, and by a proper appreciation of the salutary influence which such a rounding out of the scope of Smithsonian researches would exercise on studies in the other lines associated with the national collections.

Thus I am led to feel that the care of the public exhibits, educational and interesting though they are, after all is not the greatest duty of the Smithsonian Institution. I see in the collection of new specimens which the passage of a few more years might prevent forever; in the study of existing national collections to unlock the treasures of knowledge which they certainly contain; in the promotion of researches growing out of our expert experience in the field of radiation; in the publication of knowledge in both technical and popular forms; and in the wide diffusion of knowledge through exchanges and correspondence in all these lines, activities entirely suited to the genius and situation of the Smithsonian, which in their world-wide application and future promise, outrank in value the more local influence of the public exhibitions.

Only one thing is lacking to promote these researches. We have the foundation equipment, we have the trained experts, but we lack adequate means. The Government appropriations are mainly devoted, according to the terms of law, to expenditures incident to the preservation of collections. But a small proportion of these annual congressional appropriations is available to be expended on collecting specimens or on researches. An exception occurs, it is true, in the Bureau of American Ethnology and the Astrophysical Observatory, where research is supported by Government. For research in far eastern lands, the Freer bequest is available, but, agreeable to the donor's wishes, only in a restricted sense. Also the Roebling and Canfield foundations have made possible a certain amount of collecting in the field of mineralogy.

Aside from these and certain other lesser financial resources for specified purposes, there remains the annual income of the Smithsonian endowment, which at present yields about $65,000 annually, and such temporary grants for special researches as interested friends from time to time place in the hands of the Institution. Secretaries Henry, Baird, Langley, and Walcott all deplored the disparity between Smithsonian endowment and Smithsonian opportunity, but until recently the outlook for increased support has been

discouraging. Nor is it very adequate even yet. However, I note with satisfaction the following items of gain or promise.

1. Gifts to the unrestricted endowment from donors mentioned last year and this (approximately)	$60,000
2. Prospective bequests already disclosed (approximately)	700,000
3. Annual income set free July 1, 1928, by Government assumption of certain overhead	25,000
4. Expected royalties from Smithsonian Scientific Series for the calendar year 1928	20,000
5. Allotment for radiation research from the Research Corporation of New York	15,000

We hope to enlist the interest of other donors to build up the unrestricted endowment of the Smithsonian to such an extent as to yield an assured annual income of not less than $500,000.

While it has not been possible under existing financial circumstances to push strongly into the fields of research and publication which I have indicated above, gratifying progress has been made with the means we have. A fuller account of the researches will appear from place to place below, but I note among indications of progress the following:

1. To make space for laboratories and offices associated with the work proposed in radiation and its applications to plant growth and human health, improvements planned to include an elevator, lighting, heating, and finishing, at the estimated expense of $15,000, will make available eight rooms, each of nearly 200 square feet, in the flag tower of the Smithsonian Building, which hitherto, being inaccessible to humans, has been occupied mainly by owls, bats, and pigeons.

2. In cooperation with the New York Commission on Ventilation, Mr. Aldrich, of the Astrophysical Observatory, has done a novel, interesting, and successful research on the cooling of the human body by radiation and convection.

3. In cooperation with the Fixed Nitrogen Laboratory, research has been started on relations of radiation to plant growth and on the measurement of certain ultra-violet rays.

4. Among 30 expeditions relating to the natural-history sciences, and reported upon in later pages by the chiefs of the National Museum, the Bureau of American Ethnology, and the Freer Gallery, an important group relates to the archeology, the fauna, the flora, and the paleontology of the West Indian Archipelago. This group of islands, so near our continent, yet separated from it for several geological epochs, is of interest as illustrating the cumulative influence on life of moderate changes of environment continued over a long period of time. Other newly worked and interesting fields of recent Smithsonian exploration lie as far apart as Alaska, Mexico, South

America, South Africa, China, and the East Indies. These expeditions were mostly financed by small grants from interested friends of the Institution.

FINANCES

The permanent investments of the Institution consist of the following:

Total endowment for general or specific purposes (exclusive of Freer funds), itemized as follows	$1,594, 301. 50
Deposited in the Treasury of the United States, as provided by law	1, 000, 000. 00
Deposited in the consolidated fund—	
Miscellaneous securities, etc., either purchased or acquired by gift; cost or value at date acquired	502, 969. 00
Springer, Frank, fund for researches, etc	30, 000. 00
Walcott, Charles D., and Mary Vaux, fund for researches, etc	11, 520. 00
Younger, Helen Walcott, fund (held in trust)	49, 812. 50
	1, 594, 301. 50

The invested funds of the Institution are described as follows:

Fund	United States Treasury	Consolidated fund	Separate funds	Total
Avery fund	$14, 000. 00	$44, 244. 60		$58, 244. 60
Bacon, Virginia Purdy, fund		62, 272. 93		62, 272. 93
Baird, Lucy H., fund		1, 783. 88		1, 783. 88
Canfield Collection fund		46, 232. 86		46, 232. 86
Casey, Thomas L., fund		1, 000. 00		1, 000. 00
Chamberlain fund		35, 000. 00		35, 000. 00
Endowment fund		41, 542. 80		41, 542. 80
Habel fund	500. 00			500. 00
Hachenberg fund		5, 000. 00		5, 000. 00
Hamilton fund	2, 500. 00	500. 00		3, 000. 00
Henry, Caroline, fund		1, 425. 45		1, 425. 45
Hodgkins fund:				
General	116, 000. 00	37, 275. 00		153, 275. 00
Specific	100, 000. 00			100, 000. 00
Hughes, Bruce, fund		16, 108. 72		16, 108. 72
Myer, Catherine W., fund		18, 649. 43		18, 649. 43
Pell, Cornelia Livingston, fund		3, 000. 00		3, 000. 00
Poore, Lucy T. and George W., fund	26, 670. 00	24, 847. 89		51, 517. 89
Reid, Addison T., fund	11, 000. 00	9, 810. 48		20, 810. 48
Rhees fund	590. 00	523. 38		1, 113. 38
Roebling fund		150, 000. 00		150, 000. 00
Sanford, George H., fund	1, 100. 00	955. 18		2, 055. 18
Smithson fund	727, 640. 00	1, 516. 40		729, 156. 40
Springer, Frank, fund			$30, 000. 00	30, 000. 00
Walcott, Charles D., and Mary Vaux, fund			11, 520. 00	11, 520. 00
Younger, Helen Walcott, fund			49, 812. 50	49, 812. 50
Stock dividends not yet credited to various funds		1, 280. 00		1, 280. 00
Total	1, 000, 000. 00	502, 969. 00	91, 332. 50	1, 594, 301. 50

The Institution gratefully acknowledges gifts from the following donors:

Dr. W. L. Abbott, for archeological explorations in Dominican Republic.

Mr. William N. Beach, for expenses of naturalist in connection with African expedition.

Estate of Frederick A. Canfield, for expenses of Canfield collection of minerals.

Mrs. Laura Welsh Casey, for establishment of Thomas Lincoln Casey fund to maintain Casey collection and promote research in Coleoptera.

Estate of William H. Dall, for preparation of bibliography.

Mrs. E. H. Harriman, for purchase of Dall library.

Mr. Marcus Daly, for purchase of African natural history specimens.

Mr. Childs Frick, for further exploration in vertebrate paleontology.

New York Commission on Ventilation, for study of radiation from human body.

Mr. E. W. Marland, for Missouri Historical Society, for further studies of language of Osage Indians.

Mrs. Cornelia Livingston Pell, for care of Pell collection.

Research Corporation, for researches in solar radiation.

Mr. Charles T. Simpson, for further work on West Indian shells.

Mr. James M. Fowler, toward expenses of installing airplane, Spirit of St. Louis.

Mr. Joe Elliott, toward expenses of installing airplane, Spirit of St. Louis.

Mr. W. Sheffield Cowles, toward expenses of installing airplane, Spirit of St. Louis.

Mrs. Josephine M. Springer, for work in connection with Springer collection.

Mr. B. H. Swales, for purchase of specimens.

The Institution also acknowledges gifts for the endowment fund from the following friends:

Mr. Dwight W. Morrow.
Mr. R. D. Berry.
Mr. John F. Kennefick.

The Institution has received from the estate of George P. Hachenberg notes to the equivalent of $5,000 as a bequest to the Institution for general scientific purposes; also from the estate of Catherine Walden Myer real-estate notes to the amount of $14,618, representing final payment of bequest for purchase of works of art for use and benefit of the National Gallery of Art.

Freer Gallery of Art.—The invested funds of the Freer bequest are classified as follows:

Court and grounds fund	$394, 574. 09
Court and grounds, maintenance fund	81, 586. 40
Curator fund	330, 022. 46
Residuary legacy	3, 462, 061. 31
Total	4, 268, 244. 26

The practice of depositing on time in local trust companies and banks such revenues as may be spared temporarily has been con-

tinued during the past year, and interest on these deposits has amounted to $5,215.32. The income during the year for general expenses, consisting of interest on permanent investments and other miscellaneous sources, amounted to $63,136.14. Revenues and principal of funds for specific purposes, except the Freer bequest, amounted to $244,929.43. Cash capital from sale or call of securities other than Freer bequest (for reinvestment) amounted to $58,350.50. Revenues on account of Freer bequest amounted to $286,705.06; amount received as gain from sale of stocks and bonds, Freer bequest, was $61,069.72; cash capital from sale or call of securities, Freer bequest (for reinvestment), $519,416.35, aggregating a total of $1,233,607.20.

The disbursements, described more fully in the annual report of the executive committee, are classed as follows: General objects of the Institution, $63,663.15; for specific purposes (except the Freer bequest), $283,686.87; cash capital (except Freer bequest) reinvested, $59,157.75; Freer bequest, operating expenses of gallery, etc., $152,412.99; Freer bequest funds invested, $89,058.50; Freer bequest cash capital reinvested, $550,086.02.

The total of balances on hand June 30, 1928, of all funds, and mainly bearing interest on deposit, was $238,369.41.

The following appropriations were made by Congress for the Government bureaus under the administrative charge of the Smithsonian Institution for the fiscal year 1928:

International exchanges		$46,855
American ethnology		58,720
International Catalogue of Scientific Literature		7,260
Astrophysical Observatory		32,060
Additional assistant secretary		7,500
National Museum:		
Furniture and fixtures	$26,500	
Heating and lighting	79,500	
Preservation of collections	473,510	
Building repairs	13,000	
Books	1,500	
Postage	450	
Gallery	12,500	
		606,960
National Gallery of Art		30,356
National Zoological Park		175,000
National Zoological Park, building for birds		25,000
Printing and binding		90,000
Total		1,079,711

EXPLORATIONS AND FIELD WORK

During the past year the Smithsonian conducted 30 expeditions, a few of them financed solely from the meager funds of the Institu-

tion itself, but the majority made possible through the generosity of friends of the Institution or through arrangements with other agencies equally interested in the advancing of knowledge.

Besides 18 States of the United States, Smithsonian parties worked in Alaska, the Canadian Rockies, Labrador, Mexico, Colombia, Chile, Argentina, Brazil, the West Indies, including Hispaniola, Cuba, and Jamaica, several countries in Europe, South West Africa, Formosa, Sumatra, Siam, and China. The branches of the Institution interested in field exploration are the National Museum, the Bureau of American Ethnology, the Astrophysical Observatory, and the Freer Gallery of Art. Many of the expeditions are described in the reports of these bureaus, which form appendixes to this report, or in the Smithsonian Exploration Pamphlet, published annually.

SMITHSONIAN SCIENTIFIC SERIES

During the year a definite agreement became effective with the Smithsonian Institution Series (Inc.), of New York, to publish and distribute a series of 12 books, to be known as the Smithsonian Scientific Series, under the editorship of the Secretary. The books are intended to present an interesting picture of many of the scientific activities of the Institution and its branches, and are to be written in popular style, profusely illustrated. The first four volumes are expected to appear in the autumn of 1928 and the other eight will follow in two groups of four at intervals of several months.

The first four books were in proof at the close of the fiscal year and the others were in various stages of preparation. The titles of the first four books are as follows:

1. The Smithsonian Institution, by W. P. True.
2. The Sun and the Welfare of Man, by C. G. Abbot.
3. Minerals from Earth and Sky, by G. P. Merrill and W. F. Foshag.
4. North American Indians, compiled from the source material of the Bureau of American Ethnology by R. A. Palmer.

Two motives prompted the Institution to undertake the publication of this series: First, the desire to promote the diffusion of knowledge, and second, the desire to add to its insufficient resources for research and publication. It is hoped that the royalties accruing to the Institution from the sale of these books will continue over a long period and will contribute substantially to its available resources for scientific work.

The list of subscribers to the James Smithson Memorial Edition will be found [1] in Appendix 11.

---

[1] Brought up to date as of Oct. 15, 1928, when the manuscript of this report went to the printer.

RESEARCH CORPORATION

The Research Corporation of New York, for the administration of inventions and new industrial processes in the public interest, was founded in 1912 through the gift by Dr. Frederick G. Cottrell and his associates of valuable patents covering processes for the electrical precipitation of dust, smoke, and chemical fumes. The net profits from the commercial application of the patents are used to aid and encourage technical and scientific research. The Smithsonian has always been in close relationship to the Research Corporation, the late Secretary Charles D. Walcott having served as a director since its inception, and this year the present Secretary was elected to membership on the board of directors.

In February, 1928, the directors of the corporation having expressed an interest in the solar radiation research program of the Institution, a statement of the proposed work was given them, with the result that in March a grant of $15,000 was made to the Institution to promote investigations on the relation of radiation to the growth of plants, the effects of radiation on the health and growth of animals and human beings, and the dependence of world weather on solar radiation.

COOPERATIVE ETHNOLOGICAL AND ARCHEOLOGICAL INVESTIGATIONS BETWEEN THE SMITHSONIAN INSTITUTION AND STATE, EDUCATIONAL, AND SCIENTIFIC INSTITUTIONS

At the past session of the Congress, the following act authorizing cooperation in ethnological and archeological investigations was enacted:

[Public, No. 248, Seventieth Congress]

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Secretary of the Smithsonian Institution is hereby authorized to cooperate with any State, educational Institution, or scientific organization in the United States for continuing ethnological researches among the American Indians and the excavation and preservation of archeological remains.

SEC. 2. That there is hereby authorized to be appropriated, out of any money in the Treasury not otherwise appropriated, the sum of $20,000, which shall be available until expended for the above purposes: *Provided,* That at such time as the Smithsonian Institution is satisfied that any State, educational institution, or scientific organization in any of the United States is prepared to contribute to such investigation and when in its judgment such investigation shall appear meritorious, the Secretary of the Smithsonian Institution may direct that an amount from this sum equal to that contributed by such State, educational institution or scientific organization, not to exceed $2,000, to be expended from such sum in any one State during any calendar year, be made available for cooperative investigation: *Provided further,* That all such cooperative work and division of the result thereof shall be under the direction of the Secretary of the Smithsonian Institution: *Provided further,* That where lands

are involved which are under the jurisdiction of the Bureau of Indian Affairs or the National Park Service, cooperative work thereon shall be under such regulations and conditions as the Secretary of the Interior may provide.

Approved, April 10, 1928.

The appropriation of $20,000 authorized by the above act was made in the deficiency act, approved May 29, 1928. The following regulations for the carrying out of the project were promulgated by the Institution:

1. From the above appropriation, the Secretary of the Smithsonian Institution may approve expenditure of a sum equal to that provided by any State or educational or scientific organization, not exceeding $2,000 in any one State in any one year, when satisfied that such State or organization is prepared to contribute to such investigation, and when in his judgment cooperation by the Institution in such investigation is justified.

A. Requests for cooperation should be made by the responsible officer of the State, educational institution, or scientific organization interested.

B. Applications should be accompanied by full explanatory statements of the work proposed, the location, purpose, and any other pertinent details, the name of the field representative, if any, of the applicant, and should state whether any supervisory salaries are to be paid from that portion of the joint fund provided by the applicant; and if so, the amount thereof. It is intended that all funds provided for such cooperative work shall be devoted strictly to the prosecution of definite projects contemplated by the act and shall not be used for the payment of regular salaries or other regular expenses of any organization.

C. Applicants must present suitable evidence of the availability of funds for cooperative use and will present at regular intervals detailed accounts of expenditures therefrom. Full instructions will be furnished regarding expenditures from allotments by the Institution, which must be made to conform with the accounting regulations of the United States Treasury Department.

D. A report covering each cooperative investigation, including copies of all maps, charts, photographs, or other notes relating to the work shall be filed with the Smithsonian Institution by the leader of the joint investigation within a reasonable period following its completion. It is contemplated that a proper report embodying the results obtained will be prepared for publication by the leader or his agent within a reasonable time.

2. The act provides that "all such cooperative work and division of the result thereof shall be under the direction of the Secretary of the Smithsonian Institution." The leader of any joint investigation must be approved or designated by the Secretary, who may at any time, if in his judgment it be desirable, send a representative to the scene of operations to inspect the work, at the expense of the allotment made for the particular investigation concerned.

3. Any cooperative investigation involving lands under the jurisdiction of the Departments of the Interior, or of Agriculture, will be subject to such rules as the secretary of the department having jurisdiction may impose.

In accordance with the terms of the act cited above, an allotment of $500 was made on June 19 to Mr. P. E. Cox, State archeologist of Tennessee, to be used in conducting an ethnological and archeological survey of that portion of the proposed Great Smoky Mountains Park lying within the State of Tennessee. As the work had not actually

been begun at the close of the fiscal year, it will be described in my next report, together with such other cooperative projects as may be undertaken during the coming year under the congressional appropriation for that purpose.

PRESENTATION OF THE LANGLEY MEDAL TO COL. CHARLES A. LINDBERGH AND THE DEPOSIT OF THE "SPIRIT OF ST. LOUIS" IN THE NATIONAL MUSEUM

In my last report, announcement was made of the award on June 11, 1927, of the Langley medal to Col. Charles A. Lindbergh for his nonstop flight from New York to Paris.

The actual presentation of the gold medal to Colonel Lindbergh took place in the Smithsonian Building on December 8, 1927, at the annual meeting of the Board of Regents. In presenting the medal Chief Justice Taft, chancellor of the Institution, said in part:

Colonel LINDBERGH:

The Langley medal was established in memory of the third secretary of the Smithsonian Institution, Samuel Pierpont Langley. During the last 15 years of his life Doctor Langley's primary interest was in making possible man's flight. In this research he conducted active experiments in the lift and drift of planes, and the properties of curved surfaces, constructed large steam-driven models as early as 1896, which flew long distances, and finally he attempted to construct a man-carrying machine, which was wrecked in the two trials which it had during his lifetime. * * * Following the advice of an eminent committee of award, the medal is now presented to you, sir, in recognition of your daring nonstop flight from New York to Paris of May 20 and 21, 1927. I have the honor and pleasure of presenting the medal to you on behalf of the Regents of the Smithsonian Institution.

Permit me to add that the whole bearing and tendency of your life prior to, during, and since your memorable flight, as the light of publicity is more and more thrown upon it, has greatly enhanced the pleasure which my colleagues and I take in presenting you this award. May your future work go far to establish the dream of your desire, the wide and useful promotion of the subject of commercial aviation.

In accepting the medal, Colonel Lindbergh said:

First, I want to express my appreciation of this honor which you have just given me, and also to thank you as the board of the Smithsonian Institution for the interest you have taken in aeronautics. At a conference in St. Louis among those interested in these fields it was decided that when the *Spirit of St. Louis* was taken from service it would be offered to the Smithsonian Institution for permanent exhibition here.

The *Spirit of St. Louis* was piloted on its last flight from St. Louis to Washington by Colonel Lindbergh on April 30, 1928, and turned over to the Institution. It was placed on public exhibition in the Arts and Industries Building of the National Museum on May 13, 1928, where it faces the main entrance in a pose strongly suggesting actual flight, and immediately became the mecca for thousands of visitors

daily. It promises to be for a long time to come the most popular exhibit in the whole National Museum, and the thanks of the Nation are due Colonel Lindbergh and his friends in St. Louis for placing the famous plane in the national collection.

WALCOTT MEMORIAL MEETING

In accordance with resolutions adopted by the Board of Regents on the day following the death of Charles Doolittle Walcott, Secretary of the Institution from 1907 to 1927, a memorial meeting was held on January 24, 1928, in the auditorium of the National Museum, which was attended by a large number of Doctor Walcott's friends and official associates. Chief Justice William H. Taft, chancellor of the Institution, presided. In his introductory remarks he reviewed very briefly the many-sided career of Doctor Walcott in scientific research and in public service, and concluded by saying that the meeting was being held "in memory of a man whose work promoted real scientific investigation and discovery in his particular field, who was a shining example of a Government civil servant of the highest ideals and success, and who for 20 years gave greatly of his energies and the hardest kind of labor to expanding the usefulness of the Smithsonian Institution."

The first speaker was Dr. John C. Merriam, president of the Carnegie Institution of Washington, who considered Doctor Walcott's scientific work, emphasizing particularly his contributions to the study of the early life of the earth, as to the structure of ancient animals, their biological classification, their faunal grouping, or their succession in time. "In all these aspects of the problem," said Doctor Merriam, "his accomplishments belong to the first rank of the world's researches." He spoke also of Doctor Walcott's continuous service to the Carnegie Institution from the time of its organization until his death. He was one of the original incorporators and a member of the first board of trustees, and contributed largely to the accomplishments of the Carnegie Institution during the 25 years of his association with it.

Dr. Joseph S. Ames, professor of physics at Johns Hopkins University and chairman of the National Advisory Committee for Aeronautics, spoke of Doctor Walcott's relations with that committee. With the coming of the World War Doctor Walcott was one of the few who realized the importance of a national survey and study of aeronautics, and it was he who secured the passage of an act establishing the National Advisory Committee. His relations with it were summed up by Doctor Ames thus: "He created it; he planned its duties wisely; he guided and inspired it; he secured the appropriations for its support. Each year he took more interest and pride

in its operation. There can be no doubt that from all this he himself received his reward of pleasure and satisfaction."

Doctor Walcott's service to the United States Geological Survey was presented by Dr. George Otis Smith, director of the survey. Here was shown Walcott's exceptional capacity for the dual duties of research and administration, and during the 13 years of his directorship the Geological Survey had its greatest growth. He found time also at this period to sponsor the development of reclamation projects, national forests, national parks, fuel-testing plants, and mine-safety stations. "Charles Walcott was great as the scientist, famed the world over; he was great as the public official, honored the length and breadth of his own country; he was also great as the man in his home, among his friends in this community."

Dr. Charles G. Abbot, present Secretary of the Smithsonian Institution, spoke in conclusion of "Doctor Walcott, the Smithsonian Secretary and National Academy President." His successful methods of administration of the Institution were touched upon, and his long service to the National Academy outlined. In closing Doctor Abbot said that "the Smithsonian Institution may well be proud of its fourth secretary and the National Academy of its ninth president."

The full proceedings of the Walcott memorial meeting were printed in the Smithsonian Miscellaneous Collections, the pamphlet including a complete bibliography of Doctor Walcott's published writings, numbering 272 titles.

PRESENTATION OF PORTRAIT OF THE SECRETARY

Mrs. Samantha L. Huntley presented to the Institution a portrait of Dr. C. G. Abbot, fifth secretary. In offering the portrait, Mrs. Huntley wrote:

> It has given me much pleasure to paint this portrait, and I hope you will accept it for the Institution with my sincere wishes for your success in the administration of its affairs.

The portrait is at present hung in the National Gallery of Art.

PUBLICATIONS

The four series issued by the Institution proper are the Smithsonian Annual Reports, the Smithsonian Contributions to Knowledge, the Smithsonian Miscellaneous Collections, and Smithsonian Special Publications, while other series are published by several of the bureaus under the direction of the Institution, including the National Museum, the Bureau of American Ethnology, the Astrophysical Observatory, and the National Gallery of Art. Copies of all of these publications are distributed free to a large list of libraries.

learned societies, and specialists throughout the world, and certain of the less technical publications, such as the Smithsonian Reports and Smithsonian exploration pamphlets, are widely distributed among the general public.

In the General Appendix to the Smithsonian Report of each year are included 25 to 30 articles selected from the periodical literature of the world to show advances and interesting features of all branches of science.

During the past year the Institution published 117 volumes and pamphlets, of which there were distributed altogether 183,196 copies, including 29,720 volumes and separates of the Smithsonian Annual Reports, 26,099 volumes and separates of the Smithsonian Miscellaneous Collections, 5,878 Smithsonian Special Publications, 111,405 publications of the National Museum, and 9,126 publications of the Bureau of American Ethnology. The titles of the papers, number of pages, and other bibliographical information are given in the report of the editor of the Institution, Appendix 10.

The following sentence occurs in a letter received by the editor from the chief of the Smithsonian Division in the Library of Congress:

> The Smithsonian Report is one of the most constantly called-for publications we have here in the Library of Congress.

The annual pamphlet issued by the Institution describing the year's explorations and field work covered 30 expeditions to all parts of the world and was illustrated with 213 photographs taken by the Smithsonian field workers. An innovation in the latest pamphlet, in the desire to make it more attractive to the general reader, was to present the accounts in the form of short separate articles, written in the first person and each signed by the author, instead of as impersonal reports as heretofore.

Allotments for printing.—The congressional allotments for the printing of the Smithsonian Report to Congress and the various publications of the Government bureaus under the administration of the Institution were virtually used up at the close of the year. The appropriation for the coming year ending June 30, 1929, totals $95,000, allotted as follows:

Annual report to the Congress of the Board of Regents of the Smithsonian Institution	$11, 500
National Museum	46, 500
Bureau of American Ethnology	28, 300
National Gallery of Art	500
International Exchanges	300
International Catalogue of Scientific Literature	100
National Zoological Park	300
Astrophysical Observatory	500
Annual report of the American Historical Association	7, 000

Committee on printing and publications.—All manuscripts submitted to the Institution for publication either by members of the staff or by outside authors are referred for consideration and recommendation to the Smithsonian advisory committee on printing and publication. The committee also considers matters of publication policy. During the past year seven meetings were held and 107 manuscripts were considered and acted upon. The membership at the close of the year was as follows: Dr. Leonhard Stejneger, head curator of biology, National Museum, chairman; Dr. George P. Merrill, head curator of geology, National Museum; Dr. J. Walter Fewkes, Bureau of American Ethnology; Dr. William M. Mann, director, National Zoological Park; Mr. W. P. True, editor of the Institution, secretary; Dr. Marcus Benjamin, editor of the National Museum; and Mr. Stanley Searles, editor of the Bureau of American Ethnology.

LIBRARY

The Smithsonian library comprises the Smithsonian deposit in the Library of Congress, which is the main library of the Institution, 8 divisional libraries relating to the work of the bureaus under the Institution, and 36 sectional libraries maintained for use in individual offices. The accessions for the year, exclusive of those of the Bureau of American Ethnology, were 6,838 volumes and 16,203 pamphlets and charts, a total of 23,041 items. This brings the estimated total of volumes, pamphlets, and charts in the Smithsonian library to 709,584, not including the library of the Bureau of American Ethnology, at present administered separately by the chief of that bureau, or the thousands of volumes awaiting completion or as yet uncatalogued.

The staff was augmented by provision for a second position of assistant librarian to act as chief of the accessions department—the department which acquires publications for the library, partly by purchase and gift, but mainly by exchange.

The two most noteworthy gifts for the year were the Chinese library of the late William W. Rockhill, consisting of 1,100 volumes, presented by Mrs. Rockhill, and a collection of 3,500 serial and society publications presented by the American Association for the Advancement of Science. A large number of the latter, including some that were out of print and very rare, were needed to complete sets in the various libraries of the Institution.

As usual many volumes and parts of volumes wanted for the Smithsonian deposit in the Library of Congress were obtained, and with the reorganization of the accessions department it is expected that this service will soon be greatly enlarged. Notable progress was made on the union catalogue of the Smithsonian library, espe-

cially in connection with the Smithsonian deposit, the office library, the Langley aeronautical library, and the libraries of the National Museum and the Astrophysical Observatory. The technological library was reorganized, and the reference room was greatly improved and made more attractive.

A number of special activities were undertaken during the year, including the sorting and distribution of a large accumulation of reprints; the making of a list, preparatory to cataloguing, of some of the special collections, including the Casey, Dall, Gill, Henderson, Lacoe, Roebling, Schaus, Springer, Teller, and Vaux; and work on the reorganization of the west stacks in the Smithsonian Building.

NATIONAL MUSEUM

The appropriations for the maintenance of the National Museum totaled $650,960, an increase of $41,640 over the preceding year. A large part of the increase was for the purpose of providing for a much-needed one-rate promotion for the staff, leaving a small sum available for purchase of specimens and certain other necessary matters. A special appropriation of $12,500 permitted the construction of a gallery in the National Herbarium, which was completed during the year, nearly doubling the available space for plants.

The two most important needs of the Museum to enable it to function efficiently and expand normally are for additional personnel and more adequate housing. There are several groups of collections with no specialist in charge, and in a number of divisions there are no assistants in training to carry on the work when the older men are gone. The two buildings of the Museum are filled to overflowing, both in the exhibition halls and in the study rooms. The older structure, built in 1881, is antiquated and should be replaced by a larger and more modern one, and the newer Natural History Building should be enlarged by the addition of two wings, as originally planned for by the architect.

Additions to the collections during the year reached the total of 832,912 objects, more than twice the number received during the previous year. Specimens given to schools numbered 6,267, and more than 25,000 specimens were loaned to specialists for study. I will mention here only a few of the outstanding accessions, and others will be found listed in the report of the assistant secretary, Appendix 1.

In the department of anthropology there was received an excellent series of ivory, bone, stone, pottery, and wooden objects representative of the Eskimo culture of Nunivak Island, Alaska, collected by Messrs. Collins and Stewart, of the Museum staff; a series of objects collected by the Bureau of American Ethnology from a basket-maker village

site in New Mexico; and a collection of stone graters, pestles, celts, and clay figurines collected by Assistant Secretary Wetmore in the mountains of the Dominican Republic. In the same Republic Mr. H. W. Krieger, working under the auspices of Dr. W. L. Abbott, collected an excellent series of bone and stone implements and potsherds near Samaná Bay.

The department of biology received the large majority of the year's accessions, the total for the department being 680,350 specimens. This great number is accounted for largely by the receipt of several extensive private collections, among them the C. F. Baker collection of insects of the Philippines and the East Indies generally, bequeathed to the Museum by the late Doctor Baker; the C. G. Lloyd mycological collection of 75,000 specimens of the larger fungi; the Charles W. Hargitt collection of hydroids; and the George M. Greene collection of Coleoptera. Important collections of natural history material came from Dr. Hugh M. Smith, in Siam, and from Mr. A. de C. Sowerby, working under the auspices of Col. R. S. Clark, in China. Mr. W. L. Brown, of the taxidermy staff, joined an expedition to the Sudan and brought back a valuable set of mammals, birds, and fishes. Important collections from Hispaniola came to the Museum through the work there of Assistant Secretary Wetmore, Dr. Gerrit S. Miller, jr., and Mr. A. J. Poole. Accessions to the division of plants included 9,000 specimens collected in Honduras by Mr. Paul C. Standley and 3,000 from Formosa and Sumatra, collected by Prof. H. H. Bartlett through cooperation of the Museum and the University of Michigan.

In geology many rare and important minerals were acquired under the Roebling fund established last year. Several beautiful gems and minerals were obtained through the Chamberlain fund, including a 65-carat cut gem of alexandrite; and the Isaac Lea collection received an unusual series of cut stones of sphene given by Miss Nina Lea, granddaughter of the founder of the collection. Dr. W. F. Foshag, of the Museum staff, collected a striking group of gypsum crystals and sets of valuable ores in Mexico. The Frank Springer collection of fossil echinoderms, a complete library on this subject, and a fund to promote work in connection with the collection came to the Museum through the bequest of the late Doctor Springer. In vertebrate paleontology there were acquired a skeleton of the extinct lizard *Clidastes*, one of the rare three-toed horses from the Miocene of Wyoming, and a further series of fossil footprints collected by Mr. C. W. Gilmore.

The outstanding accession in the arts and industries department and the object of greatest popular interest to be received by the Museum in many years is Colonel Lindbergh's *Spirit of St. Louis*. Other interesting accessions in this department include the Pan

American good-will flyer *San Francisco*, a White-Stanhope steam automobile of 1901–2, a collection of ancient and modern watch and clock movements presented by the New Haven Clock Co., an automatic gingham loom of the latest type presented by the Crompton & Knowles loom works, and the apparatus used in receiving the first photoradiogram across the Atlantic on November 27, 1924, when a picture of President Coolidge was sent from London and received in New York City in the office of the Radio Corporation of America, by whom this apparatus was deposited in the Museum. The division of history received an interesting series of relics of Rear Admiral Charles D. Sigsbee, given by Mrs. Nellie C. Gunther, and a number of ancient Roman and modern European and oriental coins deposited by the Treasury Department.

The Museum took part during the year in numerous field expeditions in this country and abroad, through which large and important collections were brought back for study and exhibition. A brief account of these will be found in the report on the Museum appended hereto. The auditorium and lecture rooms of the Museum were used for 115 meetings of governmental agencies, scientific bodies, and other associations and societies. The number of visitors to the Museum totaled 1,413,286 for the year, an increase of 260,000 over the previous year. There were published 10 volumes and 59 separate papers, and 111,405 copies of Museum publications were distributed.

NATIONAL GALLERY OF ART

The need of an adequate National Gallery building is more urgent than ever. Present quarters occupied by the gallery in the Natural History Building of the National Museum are grossly inadequate and are much needed by the Museum.

At the seventh annual meeting of the National Gallery of Art Commission, a resolution was adopted favoring the assemblage at some future date of the purchases made from the Henry Ward Ranger fund since its establishment, now numbering nearly 70, in order to enable the commission to make a selection of such works as the gallery desires to claim.

Lists of the art works offered to the gallery during the year and accepted by the commission and of the accessions to the gallery collections during the year, subject to the approval of the advisory committee of the commission, will be found in Appendix 2.

Four special exhibits were held in the gallery during the year: A collection of portraits by Bernard Österman; the annual exhibit of the Society of Washington Artists; a collection of paintings by

contemporary British artists; and the annual exhibition of the Washington Water Color Club. Among the withdrawals of loans to the gallery should be mentioned 20 old masters lent by Mrs. Ralph Cross Johnson in 1924, 14 paintings by British and Dutch masters lent by Henry Cleveland Perkins, Esq., in 1922, and the John H. McFadden collection of 43 British masters temporarily placed in the gallery in 1922.

Accessions to the gallery library numbered 1,096 volumes, pamphlets and periodicals, and 12 water-color paintings by Doctor Holmes, the gift of the artist.

FREER GALLERY OF ART

Additions to the collections in the Freer Gallery during the year include two pieces of Persian pottery, three of Chinese porcelain, and six Persian paintings dating from the thirteenth to the seventeenth century. The most important addition to the library was the Chinese library of the late William Woodville Rockhill, comprising 1,100 volumes.

Two hundred and twenty-four objects were submitted for expert opinion or for translation of their oriental inscriptions, and 34 translations were made of inscriptions from photographs submitted to the curator. In answer to a constantly increasing demand, there are now available for purchase 1,491 photographs of objects in the gallery in addition to 829 negatives of the Biblical manuscripts. The gallery sold during the year 1,089 photographs, 2,017 post cards, and 1,031 copies of gallery publications.

The total attendance for the year was 111,288; of these, 1,218 came to the office for special information, to study the building and methods, to see objects in storage, to make drawings, or for similar purposes. Thirty-three classes were given instruction, four groups were given docent service in the galleries, and two lectures were given in the auditorium.

The gallery's field work in China, in charge of Mr. C. W. Bishop, was suspended, owing in part to conditions there, and Mr. Bishop returned to Washington temporarily, visiting en route important archeological collections and sites in Egypt and the principal western European countries. In Washington he has been occupied chiefly in studying the material collected during four and a half years in China. Dr. C. Li and Mr. K. Z. Tung, the Chinese members of the field staff, stayed in China to maintain the contacts established there and to prepare for future field work. Mr. Li came to Washington in the summer of 1928 to discuss plans for future work in China.

24034—29——3

BUREAU OF AMERICAN ETHNOLOGY

Dr. J. Walter Fewkes, chief of the bureau since March 1, 1918, retired on January 15, 1928, but was continued on the staff as associate anthropologist.

To facilitate the appointment of Doctor Fewkes's successor as chief of the bureau, a special unassembled examination was arranged by the Civil Service Commission, in consultation with the Secretary, for the purpose of establishing a list of eligibles. The ranking of applicants was done by a committee comprising a representative of the commission, the secretary of the Smithsonian, and Dr. A. V. Kidder, representing ethnological and archeological science at large. As a result, the appointment of Mr. Matthew William Stirling was made, to take effect August 1, 1928, just after the close of the fiscal year.

The work of the staff of the bureau has included ethnological researches relating to the Indians of the Southern States, the Sauk and Fox, the Northern Arapaho, the Mission Indians of California, the Six Nations, the Chippewa, the Winnebago, and the Osage. Archeological work by Doctor Roberts in Chaco Canyon, N. Mex., and near Arboles, Colo., uncovered interesting village sites. Cooperating with the bureau, Messrs. Judd, Krieger, and Collins, of the National Museum, made archeological investigations in Kentucky, in the Columbia Basin of Oregon and Washington, and in western Alaska. Accounts of this ethnological and archeological work appear in the reports of the bureau and the Museum.

The bureau published during the year one annual report and one bulletin, and 9,126 copies of bureau publications were distributed.

INTERNATIONAL EXCHANGES

A total of 542,233 packages of publications were handled during the year, including those sent abroad and those received for distribution in this country. The total weight of this material was 584,121 pounds, an increase of 40,996 pounds over the previous year's total.

Burma and Bombay were added to the list of foreign depositories that receive sets of United States official documents, bringing the total number of such sets sent through the exchange service to 105. Rumania, which, since 1903, has received a partial set, now receives a full set. Shipments to Turkey, suspended since the World War, were resumed, the ministry of public instruction at Angora acting as the depository. The daily issue of the Congressional Record is now exchanged for the parliamentary journals of 101 foreign governmental bodies. Brazil, the Irish Free State, and Turkey were added to the list during the year.

The Italian Office of International Exchanges, formerly under direction of the Victor Emanuel National Library in Rome, was placed under the ministry of public instruction. The Dutch Central Scientific Bureau, exchange agency for the Netherlands, is now under the direction of the Royal Library at The Hague.

NATIONAL ZOOLOGICAL PARK

Although there was no important increase in the collection of animals during the year, nevertheless a number of interesting species new to the collection was added.

The total number of animals added was 336, while 459 were lost through death, return of animals, and exchange, leaving the collection at 2,273 individuals of 582 different species. A considerable number of animals was born in the park, as usual. Among the more serious losses by death were the two giraffes, Dot and Hi-boy, secured by the Chrysler expedition, a Kadiak bear which had lived in the Park for over 23 years, the last cheetah in the collection, a jaguar, and an anaconda which had been at the Park for just 28 years, a notable record of longevity for this snake.

The attendance for the year, although somewhat smaller than last year when the animals brought back by the Smithsonian-Chrysler African expedition attracted great crowds of visitors, was nevertheless higher than for any other year in the history of the park. The total number of visitors was 2,298,449. Classes from 445 different schools visited the park, comprising 27,959 students. A number of scientific societies officially visited the park, including the American Society of Mammalogists, the American Ornithologists' Union, and the Society of Icthyologists and Herpetologists; the Vivarium Society held monthly meetings at the Park.

The new bird house, mentioned in last year's report, was completed in June, 1928, and the installation of the birds was commenced, so that the building will be opened to the public during the summer. The structure has been highly praised by officials of other zoological parks and by the public. It is divided into four rooms, together containing 145 indoor cages, and in the center is a great flight cage 58 feet long, 22 feet wide, and 32 feet high, containing rocks, a large tree, a pool, and running water.

This new bird house is a great improvement to the park, but the director calls attention to the fact that after 20 years of earnest appeal for more adequate buildings to house the splendid collection of animals, the bird house is practically the only entirely satisfactory building in the National Zoological Park, the others being a continual source of unfavorable comment by visitors. He lists seven

urgently needed structures which would cost in the neighborhood of $1,000,000, namely: 1. Exhibition house for reptiles, amphibians, and invertebrates. 2. Ape, lemur, and small mammal house. 3. Pachyderm house. 4. Remodeling of the carnivore house. 5. Antelope, buffalo, and wild cattle house. 6. A wing to be added to the bird house, with open air aviaries. 7. A proper fence around the entire park.

ASTROPHYSICAL OBSERVATORY

The three field stations of the observatory, located at Table Mountain, Calif.; Montezuma, Chile; and Mount Brukkaros, South West Africa, have continued sending to the Smithsonian results of daily observation of the intensity of solar radiation, and the United States Weather Bureau published the daily values from Montezuma on the Washington weather maps.

A statistical study of the data accumulated at the Table Mountain station led Mr. Fowle to discover a hitherto unsuspected influence of variability in the ozone content of the atmosphere. Regular observations of ozone are now made at Table Mountain in cooperation with Doctor Dobson, of Oxford, England.

A new research undertaken by Mr. Aldrich under a grant from the New York Commission on Ventilation was on the proportion of loss of heat of the normally clothed human body which should be ascribed to radiation rather than to convection by the air. Long series of novel and valuable experiments were made, using the melikeron, or honeycomb pyranometer, for observing radiation of bodies at low temperature, and a special thermoelectric temperature tester constructed for the research. The interesting results obtained, which are summed up in the director's report appended hereto, will shortly be published.

The director undertook at Mount Wilson in the fall of 1927 and again in the summer of 1928 to continue radiometer measurements of the distribution of energy in the spectra of the stars. In the 1927 experiments the radiometer vanes, made of bits of house-flies' wings, were sealed into a glass case in hydrogen, but after many trials the apparatus proved useless because the mechanism required to rotate the system so stirred up the gas that wholly unexpected motions resulted. In 1928 an optically figured, fuzed quartz cylindrical vessel was used, which was mounted on a brass support rotatable in a ground joint. With this apparatus a high degree of success was achieved, but as the results were obtained after the close of the year under consideration, they will be described in next year's report.

INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE

Since actual publication of the International Catalogue was suspended in 1922, owing to the inability of the foreign bureaus to contribute their quota of the necessary financial support, the United States bureau has continued to compile the necessary records of current scientific publications. As explained each year to Congress and to the Bureau of the Budget, the expenditures for this purpose have been kept at the lowest possible level.

An effort was made to inaugurate a practical plan for resuming publication of the catalogue and the matter is still under negotiation. It seems probable that the various countries previously represented will again cooperate by furnishing the necessary bibliographical data if the small capital fund needed to start the operation of the central bureau and begin publication can be raised.

NECROLOGY

The Institution suffered the loss by death during the year of three distinguished members of the Board of Regents—Senator Woodbridge Nathan Ferris, Mr. Charles Francis Choate, jr., and the Hon. Henry White. These three men, in serving for varying periods on the board, have aided materially in advancing the work and reputation of the Institution, and their names will be added with gratitude to the long roster of distinguished men who have so served since 1846.

Woodbridge Nathan Ferris, United States Senator from Michigan, was born at Spencer, N. Y., January 6, 1853. He was principal successively of several academies and colleges in Illinois until 1884, when he founded the Ferris Institute, of which he thereafter served as president. In 1913 he was elected Governor of Michigan, being reelected in 1915. He was elected United States Senator from Michigan for the term 1923 to 1929, but died on March 23, 1928, before the completion of his term. Senator Ferris served on the Board of Regents for three years.

Charles Francis Choate, jr., lawyer, of Boston, Mass., had at the time of his death served on the Board of Regents for a longer period than any other living member, having been first appointed on February 24, 1908. He was born at Cambridge, Mass., on October 23, 1866, and was educated at Harvard University. He became president of the Appleton Co., and was a director of the New York, New Haven & Hartford Railroad Co., the Merchants National Bank of Boston, and the American Telephone & Telegraph Co. Mr. Choate died on November 30, 1927, having therefore been a Regent of the Institution for nearly 20 years.

Henry White, diplomat, was born at Baltimore, Md., March 29, 1850. He received the degree of LL. D. from St. Andrew's University of Scotland, from Johns Hopkins University, and from Harvard University. He held various posts in the American diplomatic service, and was appointed secretary of the embassy at London in 1897. This office he held until 1905, when he was made American ambassador to Italy, and two years later ambassador to France. He represented the United States at a number of important conferences, including the Fourth Pan American Conference at Buenos Aires in 1910, when he acted as chairman of the American delegation. In 1918–19 he was a member of the American commission to negotiate peace, at Paris. Mr. White died on July 15, 1927. He served on the Board of Regents from January 15, 1917, until the time of his death.

JOSEPH NELSON ROSE

Joseph Nelson Rose, associate curator of botany in the National Museum, died at his home in Washington, May 4, 1928. Born at Liberty, Ind., in 1862, Doctor Rose received his education at Wabash College. In 1888 he was appointed assistant botanist in the Department of Agriculture. When the National Herbarium was transferred from that department to the Smithsonian Institution in 1895, Doctor Rose joined the Smithsonian's staff and here his botanical work was done for the rest of his life.

During his 40 years of original research Doctor Rose became a recognized authority on certain difficult families of plants. Most of his work was done under the Smithsonian Institution, but his well-known investigation of the cactus family was conducted under the auspices of the Carnegie Institution of Washington. In the course of this investigation he traveled extensively in the western United States, Mexico, and South America, and the results were published in four imposing volumes by the Carnegie Institution.

The gift of the private herbarium and botanical library of Capt. John Donnell Smith, of Baltimore, one of the most important ever received by the Institution, was brought about largely through the efforts of Doctor Rose. His published contributions to botanical knowledge number over 100.

IMMANUEL MOSES CASANOWICZ

Immanuel Moses Casanowicz, assistant curator of the division of Old World archeology in the National Museum, died September 26, 1927, at the age of 74. He was born at Zholudok, Russia, July 25, 1853, and studied at the University of Basle, Switzerland. Between

1880 and 1886 he was an instructor, first at the Evangelische Predigerschule at Basle, and later at the German Theological School of Newark at Bloomfield, N. J. In 1892 he received the degree of Ph. D. from Johns Hopkins University, and the same year entered the service of the National Museum, where he remained for the rest of his life.

Doctor Casanowicz was a recognized authority in the field of Old World archeology, specializing in the subject of comparative religions. He published several papers on the various religions of man, and at the time of his death another was left practically completed, which would have closed the series. He was a member of the American Oriental Society and vice president of the Anthropological Society of Washington. Doctor Casanowicz was a man of broad culture, and his place on the Museum staff will be difficult to fill.

FRANK SPRINGER

Frank Springer, associate in paleontology in the National Museum and a benefactor of the Institution, died September 22, 1927. He was born June 17, 1848, at Wapello, Iowa, and received his education at the State University of Iowa. Admitted to the bar in 1869, he went to New Mexico, where he soon became a leader of the bar of that State. He was instrumental in having a law passed by Congress establishing a tribunal for the settlement of titles under Spanish and Mexican land grants, and his greatest professional success was attained as attorney for the Maxwell Land Grant Co. He retired from active practice in 1906, and from that time on he devoted himself largely to the scientific work that he loved and that has placed him among the front rank of American paleontologists.

Doctor Springer's connection with the Smithsonian Institution began in 1911, when he brought his collection of fossil echinoderms to Washington and installed it in the National Museum, where office room and storage space for the collection were assigned him. He spent the winter and spring months of each year at the Museum carrying on his scientific work, and many of his papers were published by the Museum. His well-known quarto monographs, "The Crinoidea Flexibilia," "American Silurian Crinoids," and others were issued by the Smithsonian Institution.

By a deed of gift Doctor Springer's valuable collection and funds provided by him for its upkeep came to the Institution immediately after his death.

BRADSHAW HALL SWALES

Bradshaw Hall Swales, honorary assistant curator of birds in the National Museum, died January 23, 1928, at his home in Washington. Mr. Swales was born in Detroit, Mich., June 30, 1875, and graduated

from the University of Michigan in 1896 with the degree of LL.B., receiving his LL.M. the following year. In the latter part of 1897 he was admitted to the bar of Michigan and entered the practice of law in Detroit. In 1898 he went to Pasadena, Calif., to engage in his profession, but was forced by ill health to return east later in the same year.

Mr. Swales' interest in birds began early in life, his first published paper appearing in 1889 when he was only 14 years of age. His complete bibliography of ornithological papers numbers just over a hundred titles, a large proportion of them relating to the birds of his native State of Michigan. From 1914 he was a member of the governing board of the zoological museum at Ann Arbor, and for some years was honorary assistant in ornithology. In 1918 he was appointed honorary custodian of the section of birds' eggs of the National Museum, and in 1921 was made honorary assistant curator of birds. He contributed to the Institution a fund known as the Swales fund, through which were added to the Museum's collections many genera and species of rare foreign birds. For several years he studied the birds of Haiti, and at the time of his death, had partly completed a work on the ornithology of that island undertaken jointly with Dr. Alexander Wetmore.

Mr. Swales was a member of many ornithological and natural history societies, and was a founder of the Baird Ornithological Club of Washington, D. C.

JOSEPH MACE

Joseph Mace, driver of the Smithsonian freight wagon for over 50 years, died on January 26, 1928. Mr. Mace served the Institution faithfully and with quiet loyalty under all five of its secretaries—Henry, Baird, Langley, Walcott, and Abbot—and his devotion to duty merits the highest praise.

Respectfully submitted.

C. G. Abbot, *Secretary.*

APPENDIX 1

REPORT OF THE UNITED STATES NATIONAL MUSEUM

SIR: I have the honor to submit the following report on the condition and operations of the United States National Museum for the fiscal year ended June 30, 1928:

The total appropriations for the maintenance of the National Museum for this period amounted to $650,960, an increase of $41,640 above the appropriation for the year 1927. This additional amount included an increase of $23,510 under the principal appropriation, that for preservation of collections, which provided funds for a one-rate promotion for the staff in accordance with efficiency attained in the performance of duty as indicated in the annual survey and rating of the efficiency of all employees, the total sum required for this being $19,070. An additional $2,280 was required for additions to the salary roll through reallocations of certain employees to higher grades made by the Personnel Classification Board. The remainder, which came to $2,160, was allotted to miscellaneous purchase of specimens required for the collections, to supplies, and to additional expenditures for freight. The small amount added for the purchase of specimens has been especially important since it has brought to us material of great scientific value, and has filled gaps of long standing in our collections. An increase of $2,770 under the appropriation for furniture and fixtures allowed $770 for new curtains in certain exhibition halls in the Natural History Building, and $2,000 for storage cases, drawers for insect collections, and additional jars, vials, trays, and other devices for general use in the handling and safeguarding of our tremendous collections. The addition of $1,360 in the appropriation for heating and lighting permitted a one-rate increase to employees with proper efficiency standing on the salary roll in question. Of $1,000 added to the amount available for building repairs, $60 was for a minor promotion to one employee, and $940 was provided to cover, in part, replacement and repair on the concrete roadway on the east side of the Natural History Building. The amount of $500 additional allotted to the sum for printing and binding raised this sum to $44,000. A special appropriation of $12,500 covered the construction of a gallery over the west end of the great hall housing the collections in the Division of Plants. Construction of this gallery, which was completed during the year, practically doubled the avail-

able space for plants, and besides permitting proper expansion of the collection, allowed for the incorporation of over 200,000 specimens, the accumulation of a number of years that it had been impossible to place in their proper series because of lack of space. This gallery, next to the provision for increase of salaries, has been the most important improvement that addition to appropriations has permitted during the year.

The increase in salaries, the first promotion of the kind that has been possible since the classification act was put into effect on July 1, 1924, has resulted in appreciably higher morale on the part of the personnel and has reacted most advantageously to the Museum. All promotions have been well merited.

To look ahead to a matter not properly included in this report but one pertinent in the present connection, an additional one-rate increase was provided by Congress for the fiscal year 1929, which, with the Welch Act put in effect at the same time, has placed the staff of the National Museum generally in greatly improved economic position and has thus reacted in producing greater efficiency in the performance of the work of the Museum. To carry out the full intent of the reclassification act there is required a further general increase in pay to place those of the staff with proper efficiency rating at the average rates of their respective grades. It must be noted also that there are several groups, particularly among the skilled mechanics, where the Personnel Classification Board, recognizing that the persons in question were being paid at lower rates than in other Government departments, has given reallocations to higher positions. Promotions should be given to these persons to give them proper compensation. Further additions to the appropriations, so that the various groups of salaries may attain the averages provided by law, are earnestly urged, as such action is eminently and properly the reward for conscientious performance of duty on the part of the staff and will react wholly to the advantage of the Institution.

The question of additional personnel is one of considerable importance, as there is growing necessity for further workers, both on the scientific staff and in the clerical force. The National Museum, through the many years of its growth, has developed along broad lines and now maintains extensive collections. In several groups in these collections there is now no specialist in charge, and in a number of divisions assistants should be provided for the older men now in charge who should be training others in proper methods to carry on when they themselves are gone. Each year additional cataloguers, stenographers, typists, and laborers must be employed temporarily to assist in the work of the Museum. It is often difficult to secure employees properly equipped for this work on short notice and, further, it is not always possible to give the considerable training that may be

required for proper performance of duty in a period of limited employment. At the present time men of high scientific training must take time for routine work that could properly, and with advantage to the public welfare, be done for them by others.

Congestion in our present housing space increases annually in spite of careful effort to select for preservation only the objects that must be kept and to eliminate all material that is not permanently desired. As an asset to the Nation the collections of the National Museum should be made as complete as possible, since in many instances, unless the materials are secured now, the opportunity to obtain them will be lost. Growth in our collections is therefore steady and must continue. In the last 10 years the exhibition halls, particularly those devoted to arts and industries and to history, have become increasingly more crowded. Exhibits in the Natural History Building have been curtailed to make way for historical objects, and space designed for anthropology has been preempted for display of objects of art. All this has led, in many instances, to decided incongruity in association of exhibits, which can not be avoided under present conditions. Conditions are equally bad in the laboratories. In the entire Museum the collection of plants is now practically the only research unit that has available the requisite amount of floor space. To provide room in other laboratories there has been gradual utilization of halls designed originally for passageways, until now cases for the storage of study specimens line the walls and to some extent close these passage lanes. The situation is such that the limit of expansion is practically reached, and a number of divisions are already urgently in need of more space to house their valuable research collections. Though to one with casual knowledge it might appear that one or two examples of each kind of thing is sufficient, it is actually true that good series are imperative for the scientific investigations of the workers to whom we look for increase in our knowledge. It is found on close examination that insects, birds, mammals, fossils of all kinds, plants, mollusks, or, in fact, any other natural materials or organisms, differ from each other individually in form, color, dimension, and structure, so that a series of specimens is required to show the characteristics of a single species. Such series must be assembled in our national collections, where they will be available for the workers of the Nation, so that inevitably our research materials, as well as our exhibitions, increase and demand more room.

Further housing for the National Museum, as indicated in the preceding paragraph, is imperative. The collections in arts and industries are found at present in the old museum, a building that when completed in 1881 was a model of its kind for the world, but

with modern progress is as much out of date as vehicular transportation of the same period when compared with our modern facilities. This building should be replaced now by one of modern design, that will afford a much greater area of floor space and will have halls properly designed for modern needs in exhibition. The new building should occupy the site now given to the one in use, but should cover considerably more ground to provide the needed space. Modern advances in commerce and industry are tremendous and so overshadow their modest beginnings that these will be completely forgotten by coming generations unless the essential steps in their development are preserved. The various stages of growth in all branches of transportation, engineering, and commerce are of inestimable value in affording material stages on which further advances may be made, to say nothing of their educational importance in their effect on the minds of our modern youth. They must be carefully preserved for this purpose.

When a national gallery of art to house our wonderful art collections shall be constructed the removal of these will free a certain amount of space in the Natural History Building, but the area left vacant will be automatically absorbed by the natural-history exhibits retired originally to make room for art. There should be added to the Natural History Building two wings, one on the east and one on the west, in accordance with the original plan of the architect, which, with the same height as the present building, will give needed space for our laboratories and will house our tremendously valuable research collections. In some divisions, as, for example, the rooms assigned to the collections of insects, working conditions have become almost intolerable because of the increasing number of persons necessarily engaged in important research, so that now in some instances four persons must depend upon the light from a single window for illumination in work requiring delicate examination under the microscope. Additional space in this building would provide for a more logical arrangement of many exhibits and a remodeling of some in a more modern form, which can not be attempted at present, and would also give relief from present crowding, which often is tiring and confusing to the visitor.

The division of history, a division of the greatest importance to every patriotic American, with its wonderful series of memorabilia of those to whom we owe our country and our freedom, its collections of weapons, war materials, historical objects of all kinds, its great series of coins and stamps, at present has its exhibits distributed through the Natural History and the Arts and Industries Buildings in a manner which does not permit orderly display. There should be provided for it a separate building, where its treasures may be

adequately shown for the admiration and reverence of our people for generations to come. Certainly all these historic objects, not to be duplicated at any price, should be displayed under the best of conditions as a monument to those whom they represent and to the earlier generations of those who have built our Nation.

With increase in material wealth in the United States there has been developed a steadily growing class of persons who turn to intellectual labors for occupation and aesthetic enjoyment. Many of these, carefully trained in some one of the sciences, make definite contributions to knowledge. Others deeply interested care rather to assist in the labors of others than to make definite additions through personal efforts. All are of tremendous assistance in carrying on the important work of science. All have a sincere belief in the value of scientific research in all branches and are deeply interested in furthering it in any way possible. When it is remembered that these persons, through their economic situation, make large and definite annual contribution to the support of the Federal Government through the sums that they pay in the form of income tax, it must be admitted that it is only logical to take a small part of this contribution and devote it to the maintenance, growth, and preservation of the valuable materials found in the National Museum.

COLLECTIONS

Additions to the collections of the National Museum during the fiscal year have reached the tremendous total of 832,912 separate objects, the largest number coming to the department of biology. Material sent for examination and report amounted to 1,481 lots, including many thousands of specimens. Gifts to schools and other educational institutions numbered 6,267 specimens, while in exchange there were sent out 33,724 specimens, these being duplicate materials for which other things were received in return. More than 25,000 specimens of all kinds, many of them highly valuable, were loaned for study to specialists and other workers outside of Washington.

Following is a digest of the more important accessions for the year in the various departments and divisions of the Museum:

Anthropology.—During field work on Nunivak Island, Alaska, Mr. Henry B. Collins, jr., and Mr. T. Dale Stewart collected an excellent series of ivory, bone, stones, pottery, and wooden objects that give a comprehensive index to the culture of the Eskimo on this island. Mr. Oscar T. Crosby presented a series of specimens, personally collected, representing the ethnology of the African bushmen.

Among valuable collections which have been received through the field work of the Bureau of American Ethnology there may be mentioned especially a series of materials from a basket-maker village

site and a near-by pueblo in Chaco Canyon, N. Mex. There may be noted also a small collection of stone graters, pestles, celts, and a considerable number of clay figurines collected personally by the assistant secretary in the mountains of the Dominican Republic, and a further series of earthenware vessels and stone and bone ornaments secured by Mr. Neil M. Judd from Pueblo Bonito and presented by the National Geographic Society.

Through work financed by Dr. W. L. Abbott, Mr. H. W. Krieger secured an excellent series of bone and shell implements and potsherds near Samana Bay, Dominican Republic. Excellent series of prehistoric stone implements were secured by exchange with the Indian Museum in Calcutta, and the National Museum of Australia. Further accessions from the Old World include collections made in France by Dr. George Grant MacCurdy and deposited by the Archæological Society of Washington.

The Division of Physical Anthropology obtained a fine collection of human skeletal material from the work of Mr. Collins and Mr. Stewart on Nunivak Island already mentioned, and a further collection of skulls and skeletons from the west coast of Florida obtained by Mr. Collins, in work financed by the Bureau of American Ethnology.

Biology.—Specimens received in the department of biology during the fiscal year reached the enormous total of 680,350, a large increase over the preceding year due principally to certain extensive private collections that have come to the Museum. Chief among these is the C. F. Baker collection of insects, formed by Doctor Baker, dean of the College of Agriculture in Los Banos, P. I., and left by him on his death to the Museum. In order to obtain this material it was necessary to send Mr. R. A. Cushman, of the Bureau of Entomology, assistant custodian of hymenoptera in the Museum, to Manila to pack the collection and see that it was transferred safely to Washington, an arrangement that was possible through the cooperation of the United States Department of Agriculture. The series included is one of the finest ever assembled of the insects of the Philippine Islands, and is also rich in general East Indian material. The C. G. Lloyd mycological collection, comprising 75,000 specimens of the larger fungi, was transferred to the Smithsonian Institution during the year by the trustees of the Lloyd estate. There are included in addition 10,000 photographic negatives of fungi, a voluminous series of notes pertaining to the specimens, and a comprehensive card catalogue. The whole comprises one of the largest and most important collections in the group ever brought together. Among other accessions, the Charles W. Hargitt hydroid collection is especially important, as it represents the lifetime work of this well-known specialist.

Through Dr. Hugh M. Smith, associate curator in zoology, director of fisheries of Siam, there came important collections of mammals, birds, reptiles, fishes, insects, mollusks, and miscellaneous invertebrates. Further series came from China through the courtesy of Col. R. S. Clark from the work of Mr. A. de C. Sowerby, of especial importance being some excellent series of fishes. Through the cooperation of Mr. William N. Beach, Mr. Marcus Daly, and Mr. Osgood Field, the Museum was able to send Mr. W. L. Brown, of the staff in taxidermy, to the Sudan, where he obtained a valuable set of mammals, birds, and fishes of importance in our collections. A group of gazelles obtained will be mounted for the exhibition halls. Eight female gorilla skulls were acquired by purchase.

Mr. B. H. Swales, honorary assistant curator of birds, whose death came during the year, contributed 4 genera and 26 species of birds new to the Museum collections. The collections of Doctor Wetmore, assistant secretary, made last year when traveling under the Swales fund in Hispaniola, included series of birds, reptiles, and amphibians, and other zoological collections of a miscellaneous nature. The work of Mr. Gerrit S. Miller, jr., curator of mammals, who visited the Dominican Republic at his own expense, and that of Mr. A. J. Poole, of the division of mammals, who carried on extensive explorations in the caves of Haiti, under funds provided by Dr. W. L. Abbott, brought important collections of bones of extinct animals and birds, as well as excellent series of existing reptiles and amphibians and other specimens of value.

Among accessions in the division of insects there may be mentioned the gift of the George M. Greene collection of coleoptera, including nearly 50,000 specimens, and representing many years of careful and painstaking work. Through Dr. R. C. McGregor, the Philippine Bureau of Science has forwarded large series of Philippine insects, while other important additions to these collections have come through the work of the Bureau of Entomology. Prof. T. D. A. Cockerell presented a collection of insects from Russia and Siberia.

The Amory-Bowman Labrador expedition, arranged through cooperation with Mr. Copley S. Amory, brought collections from the coast of Labrador, including a comprehensive set of arthropods. The Bureau of Fisheries, United States Department of Commerce, transferred 5,467 specimens of marine invertebrates, the most important being from the *Albatross* expeditions of 1907–1909, which have been in the hands of specialists for study to this time, and a series of crustacea procured from Harvey C. McMillan.

Through the Frances Lea Chamberlain fund the division of mollusks obtained over 50,000 specimens of land shells from Jamaica, which were collected by C. R. Orcutt. Dr. Charles de la Torre, of

Habana, Cuba, presented 185 lots of mollusks, mostly types of new species.

In the division of plants important accessions have included 9,000 specimens collected in Honduras for the Museum by Mr. Paul C. Standley; more than 5,000 specimens, mainly grasses, transferred from the Bureau of Plant Industry; and nearly 3,000 from Formosa and Sumatra, representing a complete set of the material collected by Prof. H. H. Bartlett, collaborator of the Museum, under the joint auspices of the National Museum and the University of Michigan.

Geology.—Under the Roebling fund, established last year, there have been secured by purchase examples of four new species of minerals; some rare minerals from Franklin Furnace, N. J., now difficult to procure; a large mass of strongly magnetic lodestone from Utah, which attracts much attention in our exhibition halls; and a number of beautiful minerals for the exhibition and study series. These constitute highly important additions to our collections which otherwise it would have been impossible to procure, illustrating the value of special funds under the Smithsonian Institution for the purchase of needed specimens.

There may be mentioned also a 65-carat cut gem of alexandrite, one of the finest in existence, secured under the Chamberlain fund, together with a fine Mexican opal, a brown diamond, and some other beautiful minerals. Miss Nina Lea, grandaughter of Isaac Lea, founder of the Isaac Lea collection, presented an unusual series of cut stones of sphene. Mr. William P. Pitts, of Sunnyvale, Calif., presented five varieties of cut semiprecious stones, with examples of the rough minerals from which they were derived.

During field work in Mexico by Dr. W. F. Foshag, assistant curator of mineralogy and petrology, working in cooperation with Harvard University, groups of gypsum crystals, sets of valuable ores, and many other important specimens were collected.

Through the bequest of Dr. Frank Springer, late associate in paleontology, the Museum has received the Frank Springer collection of fossil echinoderms, together with a very complete library on this subject. The collection, considered the most complete assemblage of fossil echinoderms in the world, comprises upward of 75,000 specimens, including many types. With it has come the Springer fund, established by the donor to promote work in connection with his collection.

A second gift of value is the private collection of Paleozoic invertebrates from Dr. August F. Foerste, collaborator in paleontology, containing types of many species. The field work of Mr. E. R. Pohl in Michigan and Ontario yielded important series of Ordovician, Devonian, and Mississippian fossils.

Transfers from the United States Geological Survey have included collections of Upper Cambrian fossils secured by T. S. Lovering in Colorado, and other important collections.

The division of vertebrate paleontology acquired by purchase the skeleton of an extinct lizard, *Clidastes*, and one of the rare three-toed horses from the Miocene of Wyoming. A further collection of fossil footprints came through Mr. Gilmore's third visit to the Grand Canyon, while work in Florida by Dr. J. W. Gidley has brought important material from the Pleistocene deposits of that State.

The types of five species of fossil birds described recently by Doctor Wetmore have been deposited by the Colorado Museum of Natural History.

Arts and industries.—The single object of greatest popular interest that has come to the National Museum in many years is Colonel Lindbergh's airplane, the *Spirit of St. Louis*, deposited with the Smithsonian Institution, which has drawn large crowds since the first day of its installation. There may be mentioned also the Pan American good-will flyer *San Francisco*, transferred from the War Department, with the Army Curtiss racer airplane which won the Pulitzer and Schneider races of 1925. A Curtiss pusher type airplane of the period 1909–1914 is also an important addition. For the land transportation section there was secured a White-Stanhope steam automobile of 1901–2. Mr. Guy M. Gest, who piloted the first electric railway car operated in Baltimore in 1885, presented a series of photographic enlargements of this vehicle from his original negatives. The Hudson River Day Line presented two steamship models, one of Fulton's steamboat of 1807, and one of the *Hendrick-Hudson* built in 1906 and still in service.

The New Haven Clock Co. presented to the section of horology 75 objects illustrating ancient and modern watch and clock movements, together with an exhibit demonstrating how standard time is obtained, the whole constituting a visual history of American clock and watch making since 1775.

The Eddystone Cement Co., through Mr. E. R. Wilmer, presented a 5-foot section of an ancient Roman aqueduct built in 80 A. D. in Germany. The structure, which resembles rough concrete, is in a remarkable state of preservation, being apparently as strong to-day as ever.

The division of textiles received further exhibits dealing with rayon or artificial silk. The Crompton & Knowles Loom Works presented an automatic gingham loom of the latest type. The Bureau of Agricultural Economics of the Department of Agriculture transferred three sets of official standards of the United States for grades

of wool. A series of the new print silks, prepared by H. R. Mallinson & Co., was another important addition.

In the section of organic chemistry there was received an exhibit dealing with pyrolin, manufactured by the Du Pont Viscoloid Co., and from the Shawinigan Products Corporation a series of chemical specimens obtained from limestone and coke. An additional exhibit dealing with disease-carrying insects was prepared in the Museum during the year and added to the hygiene and sanitation collection.

In the section of wood technology arrangement was made for the loan of a collection of walking sticks belonging to Mr. Rudolph Block, the collection consisting of the interesting woods of the world prepared in the form of canes, a series unique so far as is known.

In the division of graphic arts the Misses Dodge presented a set of 24 engravings by Moseley Isaac Danforth, one of America's foremost engravers. Through exchange the division obtained a copy of a book by Dard Hunter entitled "Primitive Paper Making," made entirely by hand. Mr. William Edwin Rudge donated four examples of microform printing, including a volume of Mark Twain's The Innocents Abroad, in which 93,000 words are printed on 13 pages measuring 5¾ by 3¾ inches. A collection of the work of Henry Fox Talbot was presented by a descendant, Miss M. Talbot, O. B. E., of Lacock Abbey, Wiltshire, England. Mr. I. N. Phelps Stokes presented a series of specimens of considerable historic importance relating to Muybridge's work on motion pictures.

The Radio Corporation of America deposited the apparatus used in receiving the first photoradiogram across the Atlantic—a picture of President Coolidge sent from London and received on November 27, 1924, in the office of the company in New York City.

History.—Mrs. Agnes K. Brent, through the Missouri Historical Society, gave a silk flag presented by the ladies of Nashville, Tenn., to the Nashville Battalion during the Creek War in 1813. The naval collections were increased by a series of interesting relics of Rear Admiral Charles D. Sigsbee, given by Mrs. Nellie C. Gunther.

From the Treasury Department there was received a series of United States gold, silver, and bronze coins struck in the mints of the Government in 1927; also a series of ancient Roman and modern European and oriental coins. Mr. Isaac M. Weills presented a collection of American and European coins and tokens.

The philatelic collection was increased by more than 27,000 specimens, in part transferred from the Post Office Department and in part presented by Mr. Weills, with the coins mentioned above. Two United States 5-cent stamps found in the seam folds of the mail bag carried by Commander Byrd on his flight to France in the airplane *America* were also placed in this collection.

The Precancel Stamp Society, through Mr. Walter L. Gates, continued its development of the collection of precancel stamps, a series augmented by gifts from Mr. Gates personally.

To the Loeb collection of chemical types 102 samples were added during the year, bringing the total number of specimens to 1,092. There is assurance of hearty cooperation in developing this collection.

EXPLORATIONS AND FIELD WORK

Through explorations financed by special funds made available by friends of the Institution, through a variety of cooperative arrangements with other organizations, and to some extent from funds provided under the Museum appropriations, there have come many valuable specimens and much new information in various fields of science. A brief résumé of some of the important explorations and field work under the National Museum follows:

In the Alaskan field, Mr. Henry B. Collins, jr., and Mr. T. Dale Stewart, under funds supplied by the American Association for the Advancement of Science, the Council of Learned Societies, and the United States National Museum, conducted field work during the summer of 1927 on Nunivak Island, on the Bering Sea coast of Alaska. Explorations of several ancient village sites were carried out and anthropological measurements of the natives and observations on their social life were made. In addition much anthropological material was gathered during landings along the coast on the journey to the site of the season's investigations. The material collected includes an excellent series of skeletal remains and numerous valuable objects of material culture.

Mr. Herbert W. Krieger, through a grant from the National Academy of Sciences, and funds supplied by the Bureau of American Ethnology, visited the old site at Bonasila, Alaska, for remains that had attracted Doctor Hrdlička's attention the year before. Unforeseen high water in the Yukon prevented complete examination, but important information and specimens dealing with ancient Eskimos were obtained. He also collected ethnologica from Eskimo in several villages on the Yukon. During this same season Mr. Krieger continued archeological investigations along the Columbia and Snake Rivers, bringing in many specimens, some of which, from the Snake, appear to represent an outlying site of Pueblo Indian culture.

Mr. Neil M. Judd, on detached detail, worked for the seventh field season at Pueblo Bonito, in Chaco Canyon, N. Mex., as director of the National Geographic Society's archeological exploration of that ancient pueblo. Through the interest of the society there has been uncovered and set in order for inspection of the public one of the largest pueblos of the prehistoric period as it stood perhaps 1,000 years ago. Mr. Judd was occupied this season principally in

obtaining final data for incorporation in his report. The investigations as a whole have given extensive and valuable series of objects dealing with comparatively late pueblo culture, which through the generous gift of the National Geographic Society have greatly enhanced the Museum collections in the pueblo culture of the Southwest.

At the close of the fiscal year Mr. Judd was in the field for the Bureau of American Ethnology, examining caves in Russell County, Ky., where textiles and other interesting specimens had been exhumed.

Dr. Aleš Hrdlička, traveling partly under a grant from the Smithsonian Institution and partly at personal expense, was in Europe for seven weeks in the fall of 1927 for the purpose of viewing the latest discoveries of early man. He examined sites of important finds in southern France and then proceeded to Belgium and later to Germany, where he visited the localities in the Neander Valley typical for the race of Neanderthal man. In southern Moravia he investigated the area that had recently given important finds in Aurignacian man, and continued then to Paris for work on the material accumulated there in the Museum of Natural History and to London for examination of the collections in the College of Physicians and Surgeons. While in London he was the recipient of the Huxley medal of the Royal Society for his extensive investigations and researches in anthropology and delivered the Huxley lecture on "The Neanderthal Phase of Man."

Dr. Walter Hough in the early fall of 1927 examined for the Bureau of American Ethnology a large burial mound at Indian Mound, Tenn., to determine the type of slab-box burial. He also visited near-by village sites, flint quarries, and burial grounds, obtaining a considerable amount of material. In one of the village sites on the Cumberland River there were obtained numerous shells of mollusks of a species now extinct in that stream.

Mr. H. B. Collins, jr., during January, 1928, visited for the Bureau of American Ethnology areas near Fort Myers, Fla., where mounds of the Calusa Indian type were reported. He obtained skeletal remains of considerable importance with respect to the racial identity of this people, who, though they existed within historic times, have become extinct and are comparatively little known.

In February, 1928, Mr. H. W. Krieger, under funds provided by Dr. W. L. Abbott, proceeded to the Samana Bay region of the northeastern coast of the Dominican Republic, and there carried on archeological investigations until April, working with Mr. G. S. Miller, jr., whose interest in this matter will be discussed in a later paragraph. Mr. Krieger visited a number of caves in the San Lorenzo Bay section, excavating extensive middens found therein, and obtaining much information of value. The middens, composed principally of shells and other kitchen refuse, were in places from 4 to 8

feet in thickness, and contained artifacts of various kinds. Following this, two Arawak village sites at Anadel and the mouth of the Rio San Juan on the Samana Peninsula, whose location had been indicated by Doctor Abbott from earlier observations, were excavated carefully with the recovery of many articles of scientific importance. Officials of the Dominican Republic cooperated most courteously in furthering this work, which it is expected will be continued in the coming year.

The travels of Gabb in the seventies of the last century brought to Washington a few bones of curious mammals from the caves of San Lorenzo in the Dominican Republic, to which have been added further specimens obtained within recent years by Dr. W. L. Abbott. In May, 1927, Assistant Secretary Wetmore in travels in this region observed extensive midden deposits in these caves still untouched that gave promise of further material of importance. Mr. G. S. Miller, jr., curator of mammals, deeply interested in the extinct mammals of the island, visited this area at his own expense in February and March, 1928, accompanied by Mrs. Miller. As the excavations to be made were also of great archeological interest, Mr. H. W. Krieger, as already stated, was detailed to conduct that phase of the work through funds provided by Dr. W. L. Abbott. These joint investigations proved of great importance as there were obtained through them extensive series of bones of mammals and certain birds long extinct, from which there will come fuller understanding of their form and structure. The work was continued at the mouth of the Rio San Juan and at Anadel on the Samana Peninsula, resulting in additional osteological specimens of importance. The material obtained is now being studied.

Through the further interest of Dr. W. L. Abbott, Mr. Arthur J. Poole, of the division of mammals, was occupied from December 8, 1927, to March 21, 1928, in a thorough exploration of the well-known caves near San Michel, Haiti, obtaining large collections of bones of the extinct animals which occur in these deposits. It was particularly important that these specimens be collected at this time, since the earth on the cave floors was being removed for use as fertilizer, and in a short time all material of scientific value would have been destroyed. As incidental to this work Mr. Poole secured considerable collections of herpetological material and other zoological specimens. Reconnaissance of other caverns may indicate desirability of further work in these deposits from which many bones of mammals and birds have been obtained.

Mr. W. L. Brown, of the taxidermist staff of the Museum, was detailed to accompany an expedition to the Sudan organized by Mr. William N. Beach to secure large mammals. The original party con-

sisted of Mr. and Mrs. Beach, Mr. Marcus Daly, and Mr. Osgood Field. Sailing from Hoboken on January 4 on the S. S. *George Washington*, Mr. Brown and Mr. Field proceeded to Cherbourg, France, and from there continued by rail to Marseilles, where they joined the rest of the party and took steamer to Port Sudan, continuing from there by train to Khartoum. In a chartered boat, the *Lord Cromer*, they navigated as far as Malakal, about 50 miles up the White Nile, where the sudden illness of Mr. Beach made it necessary to return to Khartoum and prevented his continuing with the party. The others proceeded, working the territory between Khartoum and Rejaf. During 20 days in the field Mr. Daly, Mr. Field, and Mr. Brown collected many scientific specimens, as well as material for an exhibition group of gazelles, with all necessary accessories of earth, ant hills, thorn bushes, and other vegetation. Apart from the specimens obtained for the Museum collections, Mr. Brown observed in a wild state, elephants, lions, antelopes, hippos, wart hogs, buffaloes, giraffes, zebras, several cats, monkeys, crocodiles, and birds of many varieties, including the shoe-bill stork—experience of great profit to a taxidermist. He returned to Washington in April. The collections brought home included 49 mammals, 83 bird skins, 103 alcoholic birds and skeletons, and a large number of reptiles and fishes.

In November, 1927, following a stay in this country, Dr. Hugh M. Smith, director of fisheries of Siam and associate curator in zoology of the National Museum, returned to Bangkok, where he resumed active collecting of zoological materials. Word has already come of large gatherings of specimens.

In spite of the political situation in China, Mr. A. de C. Sowerby, under the auspices of Col. R. S. Clark, continued his researches and collecting. A large consignment of reptiles, fishes, and marine invertebrates has come from him during the year.

Dr. D. C. Graham, who has forwarded such splendid collections from western Szechuan, China, returned in the late fall of 1927 to Suifu, where he began at once his zoological studies. The first fruits of his endeavors have been received and include interesting collections of birds, reptiles, and invertebrates.

Dr. J. M. Aldrich, associate curator of insects, who at his own expense was in the field at the end of June, 1927, continued entomological collecting during the months of July and August at various points in the West, eastern Nevada, the higher parts of the Sierra Nevada in California, and the Yellowstone Park, which proved to be localities of greatest interest. While the principal object of his work was the collecting of Diptera, valuable material in other orders of insects was secured.

Mr. James O. Maloney, aide in the division of marine invertebrates, while on a vacation tour at his own expense, secured many valuable specimens of terrestrial isopods in Virginia, Tennessee, Alabama, and Mississippi.

At the invitation of Mr. Copley Amory, of Washington, D. C., Mr. and Mrs. Paul Bowman of George Washington University, and Doctor Bartsch, curator of mollusks, proceeded in June, 1927, to Mr. Amory's summer home on Matamek River on the north shore of the Gulf of St. Lawrence, where Doctor Bartsch initiated plans for a study of the local flora and fauna which were continued by Mr. and Mrs. Bowman until September. Mr. Amory placed a laboratory provided with the needed equipment for research and other facilities at the disposal of the party, and was ever ready to give the benefit of his knowledge of local conditions acquired through many years of residence, as well as personal help. In addition to marine dredging, careful collecting was done along the beaches, in the shallow lagoons and tide pools, and in the inland pools, lakes, and streams of the region for fresh-water organisms. Collections were secured of the ectoparasites and endoparasites of fishes and careful analyses of the stomach contents of fishes were made. Mr. Bowman devoted time to the plants, covering all groups from marine and fresh-water algae to the flowering groups. Serial cores of the peat bogs were taken and the samples shipped to Washington for microscopic study. A large amount of material, both animals and plants, was collected which is to be worked up later.

In continuation of Cerion studies mentioned in previous reports, Doctor Bartsch visited the laboratory of the Carnegie Institution at the Tortugas from August 16 to 27, 1927. The year had been an unusually dry one at the Tortugas, affecting adversely some of the groups of Cerions under observation. Visits were made to all the colonies of Cerions in the Tortugas, and material collected for study in Washington. A series of specimens of *Cerion viaregis* from the Tortugas and *Cerion incanum* from Key West, and of a hybrid Cerion from Newfound Harbor Key, were gathered and sent to Prof. Edward C. Jeffrey, Harvard University, for a comparative study of their chromosomes.

Botanical field work during the year 1927–28 has been conducted in Honduras by Mr. Paul C. Standley, associate curator; in the islands of Formosa and Sumatra by Prof. H. H. Bartlett, collaborator; in Texas by the late Dr. J. N. Rose, associate curator; in Oregon and Washington by Dr. A. S. Hitchcock, custodian of grasses; and in California by Mr. J. R. Swallen, assistant in the grass herbarium. Mr. Standley's botanical exploration in Honduras was made possible by the generous cooperation of Prof. Oakes Ames, of Harvard University, and the United Fruit Co. Work began in December

and was conducted from headquarters at Tela, being mainly confined to the lowlands and adjacent low mountains along the north coast. During four months upward of 9,000 specimens were collected, these representing the largest single botanical collection ever procured in Honduras. The material is of unusual interest, since it contains many new specimens and others not known previously from that region. Professor Bartlett's field work in Formosa and Sumatra, financed from personal funds, was conducted under the joint auspices of the National Museum and the University of Michigan. The period of exploration in Formosa, though short, yielded specimens of many endemic species, chiefly from the higher mountains, which were not previously represented in American herbaria. In Sumatra the field work was continued from December, 1926, to the middle of July, 1927, and resulted in the accumulation of a large collection consisting of about 2,400 numbers, mostly represented by 5 to 10 specimens each. The exploration included the ascent of several volcanoes and lesser mountains and a reconnaissance of the Asahan region. The importance of this collection can scarcely be overestimated in view of the rapid destruction of the Sumatran jungle, whose components are still very imperfectly known.

In connection with current investigations of native plants as potential sources of rubber, the late Dr. J. N. Rose, associate curator of plants, was detailed to field work in Texas during October and November, 1927, through funds supplied by Mr. Thomas A. Edison. From the economic standpoint the results were chiefly negative, but a considerable collection of herbarium material was obtained for use in other current studies, chiefly an investigation of the families Caesalpinaceae and Mimosaceae. In this work Doctor Rose was accompanied by Mr. Paul G. Russell, on detail from the Bureau of Plant Industry.

Field studies of grasses for the United States Department of Agriculture were conducted during the summer of 1927 in the Pacific coast region of the United States by Dr. A. S. Hitchcock, custodian of the section of grasses, and Mr. J. R. Swallen, assistant in the grass herbarium. Doctor Hitchcock spent about 10 weeks in the mountains of Oregon and Washington, in cooperation with the Forest Service, and a similar period was spent in California by Mr. Swallen. In both cases the object of the investigation was to determine the amount and character of variation in the grass species due to environmental and other factors, and to discover differential characters for the various species. Excellent collections of illustrative material were obtained. At the present time Mr. Swallen is absent on a similar field trip in the southwestern United States.

Under an allotment from the Roebling fund, Dr. W. F. Foshag visited several mineral localities in the State of Sonora, Mexico. The

chief point of interest was the Chispas mine, near Arispe, where Doctor Foshag procured a series of the magnificent silver minerals found there. During several days spent at Bisbee, Ariz., in collecting minerals and examining material offered for sale, some very interesting specimens were added to the collections. In cooperation with the mineralogical museum of Harvard University, and accompanied by a representative of that institution, Doctor Foshag spent three months collecting minerals and examining mineral deposits in the States of Guanajuato, Zacatecas, Durango, and Chihuahua, Mexico. A considerable amount of excellent exhibition and study material was obtained, including groups of large gypsum crystals, a fine series of lead and zinc minerals, and complete sets of ores and rocks from all of the important mining districts visited. These will be used as the basis of a report on these districts.

Drs. C. E. Resser and R. S. Bassler spent two months in the Rocky Mountain region in a reexamination of certain Canadian sections for stratigraphic details necessary for the completion of Doctor Walcott's unfinished manuscript summarizing the knowledge gained in his years of extensive research. The area examined was covered by motor and the researches were at various times greatly facilitated by the cooperation of other geologists familiar with local sections. The territory covered included the Wasatch Mountains, Yellowstone National Park and the mountains immediately north, and the area along Newland Creek, Meagher County, Mont. Stops were also made in the Little Belt Mountains. The main objective of the summer's work, however, was the general region of the Bow Valley, Canadian Rocky Mountains, north and west of Banff, Alberta, and certain other localities well known from Doctor Walcott's investigations.

In cooperation with the Milwaukee Public Museum, Dr. Erwin Pohl continued a detailed study of the little known but highly important stratigraphy of the Middle Paleozoic of the mid-Eastern and Central States. The researches of the season covered portions of eastern Wisconsin, southern Michigan, northern Ohio, and southern Ontario. Nearly 2 tons of selected and beautifully preserved fossils resulted from the trip.

Dr. Joseph A. Cushman, collaborator in paleontology, spent the greater part of the summer of 1927 in a field trip through various countries of western Europe primarily to secure collections of fossil foraminifera from classic areas. He was highly successful in his work, and as a result, large numbers of types will come to the Museum upon the completion of his studies.

Late in the fiscal year Mr. Gilmore was detailed for an expedition in the Two Medicine formation in Montana to search for dinosaur and other vertebrate remains, with Mr. George F. Sternberg, who has had long and varied experience in fossil collecting, as his assist-

ant. Incomplete reports to date indicate the finding of valuable material. As the expedition will continue into the next fiscal year, a detailed report will be given later.

Exploratory work in the Pleistocene was again taken up by Dr. J. W. Gidley at Melbourne and other localities in Florida. The expedition, which covered a little more than two months, was made possible through the generosity of Mr. Childs Frick, who furnished half of the funds necessary for carrying on the work, the remainder coming from the Smithsonian Institution. Doctor Gidley was assisted by Mr. C. P. Singleton, of Melbourne. Two principal problems involved in this research included the further search for evidence on the contemporaneity of man with an extinct fauna in Florida, a much-disputed question, and the collection of additional material for the purpose of fixing more definitely the age of this fauna. The results in both cases are regarded as highly satisfactory.

BUILDINGS AND EQUIPMENT

Minor repairs of various kinds have been required to keep the buildings housing the Museum in proper condition during the year. In the Natural History Building, woodwork of windows on the ground and third floors was repainted, and the interior woodwork on windows on the third floor was refinished. The ceiling and walls in the bird range were pointed up and painted, and wooden floors in rooms occupied by the division of mammals and the Biological Survey and in the office of the assistant secretary were refinished. Tin-lined gutters on the roofs were given a coat of metallic and oil paint; broken glass in various windows was replaced; wooden ladders were installed for use in inspecting the walls supporting the dome on the attic floor, and down pipes leading from the roof were repaired.

In the Arts and Industries Building metal roofs were repainted, ventilating windows were repaired and provided with screens, and wooden window frames and sash recoated with lead and oil paint. The southwest range was repainted, as well as the gallery, and an iron-pipe railing installed on the latter to replace a temporary guard rail formerly in use. The composition floor of the reading room in the library was covered with cork carpet. A wire screen partition was built on the third floor of the northeast pavilion to prevent unauthorized persons from entering the Mechanical Technology Laboratory; a concrete floor was laid about the mine exhibit in the southwest pavilion; and sheet-iron hoods were made for radiators in the Lace Hall to protect the walls from accumulation of dirt.

In the Smithsonian Building a hot-water system was installed; stairs leading to the comfort rooms were repaired; the doors in the disbursing agent's office were remodeled; the east entrance vestibule

was repaired and painted; and doors in the storage room were made fireproof by covering with sheet iron.

The exterior of the Aircraft Building was repainted and broken glass replaced.

The work of replacement of the main portion of the concrete service road east of the Natural History Building was continued, 180½ linear feet being laid during the year.

The power plant was in operation from September 21, 1927, until May 29, 1928. The consumption of coal was 3,416 tons, an amount in excess of that used in 1927. The average cost of coal was somewhat greater than for the preceding year, being $5.87 per ton. The Steamboat Inspection Service of the United States examined the boilers during the summer and reported them in good condition, stating that they complied with all regulations governing steam boilers of this type. The elevators have been regularly inspected by the District of Columbia inspector, and are now equipped with all necessary safeguards to protect passengers. The total electric current produced amounted to 603,343 kilowatt-hours, manufactured at a cost of 1.89 cents per kilowatt-hour, including interest on the plant, depreciation, labor, and material. The engineer reports a decided increase in efficiency in the production of electric current, due to installation of new pistons in the operating engines, an essential increase, as the demands for light and power from all the buildings grow larger each year. The ice plant manufactured 354.3 tons of ice at an average cost of $2.41½ per ton, which is slightly less than the cost for the previous year.

During the year 23 exhibition cases and bases, 226 pieces of storage, laboratory, and office furniture, and 2,178 drawers of various kinds were added, practically all of these being manufactured in our shops.

MEETINGS AND RECEPTIONS

The lecture rooms and auditorium of the National Museum during the present year were used for 115 meetings, which covered a wide range of activities. Governmental agencies that utilized these resources for hearings, meetings, lectures, and exhibitions of pictures included the Commission of Fine Arts, the Graduate School of the United States Department of Agriculture, the Federal Horticultural Board, the Forest Service, the Federal Radio Commission, the Bureau of Plant Industry, and the Extension Service of the United States Department of Agriculture.

Members of the Forest Service held a series of meetings during the year dealing with various phases of their work. The Smithsonian staff was convened on February 17, 1928, for an address with motion

pictures by Mr. Matthew W. Stirling on his expedition to New Guinea, which was carried on in cooperation with the Smithsonian Institution.

Scientific societies that met regularly in the building included the Entomological Society of Washington, the Society for Philosophical Inquiry, the Anthropological Society of Washington, the American Horticultural Society, and the Wild Flower Preservation Society. Meetings were held also by the American Society of Mechanical Engineers, aeronautic division; the Washington Society of Engineers; the Potomac Garden Club; the Washington Society of Fine Arts; the Washington Academy of Sciences; the Seymour Club; the District of Columbia Federation of Music Clubs; the District of Columbia Library Association; the American Surgical Association: and the American Association for Thoracic Surgery.

The American Ornithologists' Union was convened for its annual meeting from November 15 to 17, inclusive. The American Society of Mammalogists held its annual meeting from April 11 to 13, and the annual meeting of the American Society of Ichthyologists and Herpetologists was convened on April 16.

The World Unity Foundation held a meeting on February 21 for addresses by Herbert Adams Gibbons, of Princeton University, and Felix Valyi, of Geneva, Switzerland. The Masonic Clubs of the District of Columbia met on February 22, under Gen. Amos A. Fries, for an address by Judge James W. Witten. The American War Mothers, District of Columbia Chapter, met on April 27 for addresses by Representative Royal C. Johnson, of South Dakota, and Gen. Amos A. Fries. Music was furnished by the United States Marine Band.

The Fifth National Oratorial Contest was held in the auditorium on May 10. The Fourth Annual National Spelling Bee came on May 22, with 25 boys and girls entered for the contest. The first prize was won by Miss Betty Robinson, representing the South Bend News-Times.

The Veterans of Foreign Wars of the United States, Federal Post, No. 821, United States Department of Agriculture, met on May 28 for addresses by R. W. Dunlap, Assistant Secretary, United States Department of Agriculture, and Maj. Gen. Charles P. Summerall, United States Army. Music was furnished by the Navy Band.

Other agencies using the auditorium or lecture room included the Washington Times, the National Association of Retired Federal Employees, classes from George Washington University and Howard University, the Boy Scouts, groups from the public schools of the District of Columbia, and the Smithsonian Relief Association.

On January 24, 1928, at 11 a. m., there was held a special memorial meeting under direction of the Board of Regents of the Smithsonian Institution to commemorate the life and work of Charles Doolittle Walcott, fourth Secretary of the Smithsonian Institution. The gathering was presided over by the chancellor of the Institution, the Hon. William Howard Taft, Chief Justice of the United States. Addresses were delivered by Dr. John C. Merriam, representing the Carnegie Institution of Washington; Dr. Joseph S. Ames, for the National Advisory Committee for Aeronautics; Dr. George Otis Smith, for the United States Geological Survey; and Dr. Charles G. Abbot, for the National Academy of Sciences and the Smithsonian Institution.

Special exhibitions in connection with various meetings included an historical exhibit dealing with ornithology arranged in connection with the convention of the American Ornithologists' Union during November, and one concerned with the work of American artists portraying mammals in connection with the annual meeting of the American Society of Mammalogists from April 1 to 15.

On the evening of February 28 members of the Geological Society of Washington were given a special view of the geological collections in the National Museum. From March 1 to 3 there was a special display of the work in nature study in the fourth to the eighth grades in the District of Columbia schools arranged under Miss Esther W. Scott, teacher of elementary science.

On June 21 there was a special meeting in the Arts and Industries Building of a group of 100 persons representing the Chamber of Commerce of St. Louis and other backers of the Lindbergh flight, who assembled for a ceremony beneath Colonel Lindbergh's plane, the *Spirit of St. Louis*, when a silver medal commemorating the first New York-to-Paris flight was presented to the Smithsonian Institution. The Secretary responded with a brief address, in which he expressed the thanks of the Institution to those closest to Colonel Lindbergh in his great venture for the privilege of exhibiting the plane in the Museum halls.

MISCELLANEOUS

The exhibition halls of the National Museum were open during the year on week days from 9 a. m. to 4.30 p. m., while in addition the Natural History Building and the Arts and Industries Building were opened Sunday afternoons from 1.30 to 4.30. From January 22 to the close of the year the exhibits in the Smithsonian Building were also opened to the public on Sunday afternoon for the hours indicated. All buildings were closed on Christmas Day and New Year's Day.

Visitors to the Museum during the year totaled 1,413,386 persons, an increase of more than 260,000 over the previous year, an excellent index to the number of Americans who come to visit the National Capital. Attendance in the several buildings was recorded as follows: Smithsonian, 175,190; Arts and Industries, 517,238; Natural History, 618,773; Aircraft, 102,185.

The average daily attendance for week days was 3,901 and for Sundays 3,761. The public has shown great appreciation of the privilege of entrance to our exhibits on Sunday afternoons.

During the year the Museum published 10 volumes and 59 separate papers, while the distribution of literature amounted to 111,405 copies of its various books and pamphlets.

Additions to the Museum library have included 3,015 volumes and 1,165 pamphlets, obtained partly by exchange and partly by donation. The library of the National Museum, as separate from that of the Smithsonian Institution proper, has now 72,315 volumes and 106,881 pamphlets. Though most of the accessions for the present year, as usual, came through an exchange of publications, there may be noted the donation of 595 volumes and many additional separate papers from the American Association for the Advancement of Science, among them many works now out of print and very rare, which have served to complete a number of important sets on our shelves. Mr. William K. Vanderbilt presented a copy of his privately printed work entitled "To Galapagos on the *Ara*." Mr. Thomas A. McCaslin presented a bound manuscript entitled "A Souvenir of Wyoming," including a diary of a trip in Jackson Hole and Yellowstone Park, with many remarks on early history and historical geography. The Librarian of Congress transferred 68 volumes and 47 parts to supplement our reference works, and about 300 volumes, chiefly on the religions of the Old World, were received from the estate of Dr. I. M. Casanowicz, late assistant curator of the division of Old World archeology. During the year the library staff completed the sorting of a large accumulation of reprints, which were placed in the hands of the curators to whose work they were most related. A number of special collections of books, including the Casey, Dall, Gill, Henderson, Lacoe, Roebling, Schaus, Springer, and Teller libraries were listed in preparation for cataloguing.

Dr. Samuel W. Woodhouse, for some time associated with the Institution in connection with the art collections presented to the National Gallery of Art by the late Alfred Duane Pell, was given honorary appointment as collaborator in ceramics. Mr. Robert A. Cushman, of the Bureau of Entomology, United States Department of Agriculture, was made assistant custodian of hymenoptera. Mr. Arthur Cleveland Bent, of Taunton, Mass., well known for his comprehensive volumes on the life histories of North American birds,

was appointed collaborator in the division of birds. Dr. Joseph A. Cushman, an international authority on foraminifera, was appointed collaborator in foraminifera in the division of marine invertebrates. Dr. W. T. Schaller was given honorary appointment as associate in mineralogy in the department of geology.

Mr. Ellsworth P. Killip, aide in the division of plants, was advanced on December 1 to assistant curator and, following the resignation of Mr. Paul C. Standley on May 31, to associate curator. On June 1 Mr. Emery C. Leonard was made assistant curator in the division of plants. Miss M. F. Willoughby was appointed senior clerk in the division of stratigraphic paleontology on December 16. The division of Old World archeology, following the death of Dr. Casanowicz, has been placed temporarily under the general supervision of Mr. Neil M. Judd, curator of American archeology.

Turnover on the staff for the year was less than for the similar preceding fiscal period, due to the action of Congress in making possible on July 1, 1927, the first promotions under the efficiency ratings. The Museum force has now become more stabilized, with resultant improvement in morale.

Three employees left the service through the operation of the retirement act: Columbus M. Sorrels, watchman, after 36 years' service; Robert Campbell, a laborer at the Museum for 33 years; and Thomas Hamilton, laborer, after 23 years of service.

Miss Elizabeth Ward Lamon, principal clerk-stenographer in the administrative office, after a Government service of 30 years, was granted an indefinite furlough to permit her to regain lost health.

The Museum lost through death a number of important members of its scientific staff, all of whom had been long associated with its scientific work. Dr. Immanuel Moses Casanowicz, assistant curator of Old World archeology, died September 26, 1927. Dr. Joseph Nelson Rose, assistant curator of plants, died May 4, 1928. Mr. Bradshaw Hall Swales, honorary assistant curator of birds, died on January 23, 1928. Other losses by death included Mr. Joseph Mace, who served the Museum as teamster for over 50 years; Bernard W. Burdine, oiler, with 40 years of service; Samuel J. Lancaster, watchman, with 33 years of service; Carter E. Collins, laborer for 30 years; Edwin J. Weiskoff, electrician for 17 years; Edgar Furbush, watchman for 6 years; and Frank Nash, laborer for 2 years.

Respectfully submitted.

Alexander Wetmore,
Assistant Secretary.

Dr. Charles G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 2

REPORT OF THE NATIONAL GALLERY OF ART

SIR: I have the honor to submit the following report on the affairs of the National Gallery of Art for the fiscal year ending June 30, 1928:

The urgent need of a national gallery building has been a chief concern of the gallery staff and of the commission during the year. The poverty of space for the installation of collections already in hand and for the encouragement of gifts and bequests of art works, the sources of our present riches, has interfered seriously with progress in any direction. It is to be hoped that this condition may soon be remedied. Upward of a year ago it was announced in the public press that, under certain suggested conditions, private funds would become available for the erection of a building. There is naturally less inclination in Congress to consider grants for art while the prospect of private munificence for this purpose is thus definitely foreshadowed. Moreover, the project of a great group of buildings, manifestly necessary to the public welfare and requiring vast expenditure of the public funds, took shape about this time and is now being carried forward with commendable vigor. It is thus apparent that for the present the realization of the gallery's hopes seems dependent on the generous response of public-spirited citizens to a manifest need. Undue delay in the struggle for national art appears as a great misfortune, since we are compelled to remain inactive during a period of exceptional art activity and art production and distribution, and in which the art treasures of the Old World are in a state of unparalleled flux.

THE GALLERY COMMISSION

The art collections of the Institution, which accumulated slowly during the last quarter of a century, and largely within the department of anthropology of the National Museum, had, in 1920, grown so in bulk that the Regents of the Institution found it advisable to establish the National Gallery as a separate bureau of the Institution, and a commission was appointed to consider its interests and promote its welfare. This commission comprises 16 members—5 public men interested in the fine arts, 5 experts in the fine arts, and 5 artists, the

Secretary of the Institution becoming a member ex officio. The membership at present is as follows: W. K. Bixby, Joseph H. Gest, Charles Moore, James Parmelee, Herbert L. Pratt, John E. Lodge, Frank Jewett Mather, jr., Charles L. Borie, jr., Edward Willis Redfield, James E. Fraser, Edmund C. Tarbell, Daniel Chester French, Herbert Adams, Gari Melchers, William H. Holmes, and C. G. Abbot, ex officio.

The Regents' plan provided for two or more meetings of the commission per year, but it was soon found that a single meeting only was necessary to look after the affairs and to consider the problems of the gallery. Meetings were held annually beginning in 1921, and their proceedings are recorded in the annual reports of the Smithsonian Institution.

The seventh annual meeting of the commission was held in the Regents' room of the Institution on December 6, 1927. The members present were Gari Melchers, chairman; Frank J. Mather, jr., vice chairman; W. H. Holmes, secretary; Herbert Adams; James E. Fraser; John E. Lodge; James Parmelee; E. W. Redfield; and C. G. Abbot, Acting Secretary of the Smithsonian Institution.

The annual report of the secretary of the commission reviewing the activities of the gallery for the calendar year 1927 was then presented. There was wide discussion of various matters treated in the report, especially (1) the question of the development of a national portrait gallery as a separately conducted branch of the gallery proper, and (2) the possible assemblage in the gallery at a future date of the Ranger-fund purchases now tentatively held by various galleries throughout the country, the National Gallery having the privilege of claiming such of these works, now numbering upwards of 60, as it may choose, after the lapse of a certain period. The purpose of the proposed assemblage is to enable the commission to keep in touch with the growing collection and to make tentative selection of such works as appear worthy of a place in the National Gallery. On motion of Mr. Adams, it was resolved that in the sense of the meeting it is desirable to hold such an exhibit of the Ranger purchases. On motion, it was further resolved that the Secretary of the Smithsonian Institution be invited to ask the Bureau of the Budget to recommend an appropriation of $1,000 to meet the expenses of the proposed exhibition of the Ranger paintings.

The secretary presented a request of the National Press Club of Washington for the loan of gallery paintings for the embellishment of the club's reception rooms and principal offices, and after discussion, on motion of Mr. Mather, it was *Resolved:* That it is the policy of the National Gallery of Art not to lend works of art of public ownership to private institutions.

Following adjournment at noon the advisory committee visited the gallery rooms in the National Museum Building to consider acceptance of offerings of art works for the year. The following were accepted: (1) Seven water-color paintings of Greek Temples, by Henry Bacon, designed to serve as a nucleus for a prospective architectural department in the gallery; (2) a three-quarters length portrait of Admiral Samuel Francis Du Pont, by Daniel Huntington, for the National Portrait Gallery; and (3) portrait busts of Gen. Winfield Scott and William Cullen Bryant, by Henry Kirke Brown, for the Portrait Gallery.

THE HENRY WARD RANGER FUND PURCHASES

The paintings purchased during the year by the council of the National Academy of Design from the fund provided by the Henry Ward Ranger bequest, which are under certain conditions prospective additions to the gallery collections, are as follows, including the names of the institutions to which they have been assigned:

Title	Artist	Date of purchase	Assignment
63. Cypripedia	Sergeant Kendall, N. A.	December, 1927	
64. The Chief's Canoe	Belmore Browne	do	National Gallery of Art, Washington, D. C.
65. Feeding Cattle, Winter	Harry Leith-Ross	do	Montana State College, University of Montana, Bozeman, Mont.
66. Ice Pond	Aldro T. Hibbard, A. N. A.	do	Phillips Andover Academy, Andover, Mass.
67. A Long Island Garden	Childe Hassam, N. A.	do	The Kansas City Art Institute, Kansas City, Mo.
68. Mlle. Maria Safanoff	Irving R. Wiles, N. A.	April, 1928	

THE ALFRED DUANE PELL COLLECTION

Thirty-six pieces of porcelain were added to the Alfred Duane Pell collection, already installed, by Mrs. Pell, Mr. Pell having died March 6, 1924. The lot includes 10 superb pieces of pate-sur-pate by Solon and 4 by his pupil, A. Birks; 6 pieces of charming Old Worcester ware; 1 piece of the hitherto unrepresented New Hall porcelain; 1 piece of Meissen from a set made for the King of Holland; and examples of Capo di Monti, Doccia, and other Italian porcelains. The pieces by Solon are of special interest in rounding out the gallery's exceptional representation of this great master's work.

THE GEORGE DUPONT PRATT GIFT

The Thomas Moran painting of the Grand Canyon of the Yellowstone which has been exhibited in the gallery for a number of years

as a loan, first by the artist and later by his daughter, Miss Ruth B. Moran, has been added to the gallery's permanent collections. In May of the present year during a visit of Mr. Pratt to the gallery he became deeply impressed with the national importance of this great work, and soon after announced his willingness to contribute $10,000 to its purchase. Miss Moran was so greatly pleased with the prospect of having the picture become the property of the Nation, thus retaining its place in the National Gallery, that she decided to accept this amount. Moran may well be regarded as our greatest master of landscape, marvelously skilled with the pencil, the graver, and the brush, and he was a colorist unsurpassed. After three visits to the Yellowstone he chose this as the subject most worthy of his crowning effort, and prepared the way for its realization by a multitude of studies in pencil and water color. The canvas finally chosen was so large—8 by 14 feet—that it could not be accommodated in his East Hampton studio and a near-by carpenter shop was utilized for the purpose. The acquirement of this work is a triumph for the National Gallery.

SPECIAL EXHIBITS HELD IN THE GALLERY

With the opening of the calendar year 1928 the gallery entered upon a period of exceptional activity. Four important exhibits followed one another in quick succession. The space required for their installation was obtained by removing to storage the contents of four of the main exhibition rooms of the gallery. This was made less embarrassing by the withdrawal at the particular moment of the McFadden collection of British old masters, which had occupied two of the rooms for a number of years awaiting the completion of the Philadelphia Museum of Art, in which institution they are destined to find a permanent resting place.

THE ÖSTERMAN COLLECTION

It happened also at this time that the Henry Cleveland Perkins collection of British and Dutch masters, exhibited for several years in the northeast room of the gallery, was withdrawn, and in this room the first of the series of exhibits, the remarkable collection of portraits with one figure subject, by Bernhard Österman, of Stockholm, Sweden, was installed. This exhibit, held under the patronage of His Excellency, W. Boström, the Swedish minister in Washington, was opened to the public January 11, a private view by special invitation having been given on the 10th. An illustrated catalogue was supplied by the artist, the foreword to which, by Christian Brinton, is in part appropriately quoted in this place.

The present exhibition offers a comprehensive résumé of Mr. Bernhard Österman's work. From the early likeness of the ascetic, intellectual Bishop of Lund to the latest products of his brush you observe an increased mastery of the approved elements of pictorial representation. For aristocratic restraint, coupled with clearly realized individuality, special mention must be made of the seated figure of His Majesty the King of Sweden. In sheer vigor of characterization the standing three-quarter length of Herr von Stubenrauch, late president of the Berlin police, occupies a position by itself in the artist's gallery of international celebrities.

It happened that this collection at the close of the exhibition, January 24, was not scheduled for exhibition elsewhere for the remainder of the season and the artist consented to have it remain on view in the gallery until the next exhibition season opens.

ANNUAL EXHIBITION OF THE SOCIETY OF WASHINGTON ARTISTS

Early in 1928 it became known that the Corcoran Gallery, due to the erection of the W. A. Clark Annex and the installation of his great collection, could not hold the accustomed annual exhibits of the local art societies. A plea was made by the artists, who were at a loss for accommodations, to the director of the National Gallery who was glad to grant the request, although the granting implied a very great crowding of the season's exhibits. The annual exhibition of the Society of Washington Artists followed the Österman exhibit and was opened to the public February 4. The society printed its usual catalogue, which listed 119 paintings and 11 works of sculpture. The installation in the three available halls of the gallery proved highly satisfactory to the society and the exhibit met with marked public appreciation.

COLLECTION OF CONTEMPORARY BRITISH ART

The exhibit of the local society was followed by a most interesting collection of paintings, 91 in number, by contemporary British artists, which remained on view from March 5 through April 1. The paintings were assembled in London by Miss Charlotte Pearson with the approval of the president of the Royal Academy, who named as an honorary committee the Earl of Balfour, K. G., the Earl of Birkenhead, K. G., Sir Frederic G. Kenyon, G. B. E., and His Excellency the Hon. Alanson B. Houghton, ambassador of the United States to Great Britain. The committee of selection was composed of Robert Anning Bell, R. A., Sir D. Y. Cameron, R. A., Sir George Clausen, R. A., Julius Olsson, R. A., and Miss Charlotte Pearson, secretary, who accompanied the collection to Washington, and at the close of its presentation here directed its transfer to the Toronto Art Gallery, Toronto, Ontario, Canada.

The exhibit was held under the patronage of His Excellency Sir Esme Howard, G. C. M. G., the British ambassador to the United

States, and was opened by a public reception tendered by the Board of Regents of the Institution. The foreword of the catalogue, by Sir Frederic G. Kenyon, G. B. E., was introduced by the following lines:

The object of the present exhibition is to bring to the notice of the American people some part of the contemporary work of the artists of Great Britain. It has the support of many of its leading painters, and it is believed that it may fairly claim to be representative of much of the best work that is being done there to-day. Merely as an exhibition of art it is hoped that it has attractiveness and merit.

ANNUAL EXHIBITION OF THE WASHINGTON WATER COLOR CLUB

The annual exhibition of the Washington Water Color Club followed the British exhibit and closed the loan exhibition program for the season. There were 226 exhibits—185 in water colors and 41 etchings, block prints, and drawings. The result in this case, as in that of the local oil exhibit, was highly satisfactory. The works were well shown and the attendance was gratifying.

It may be stated in this place that it is not a definitely authorized privilege of the gallery, which is a Government bureau, to entertain displays for individuals or private organizations of which an essential feature is the privilege of making sales. The admission of the exhibits of the two local societies was, as stated above, due to a serious emergency that had arisen, and no objection has been raised.

THE JOHN ROSS KEY COLLECTION OF PAINTINGS

In January, 1927, the gallery accepted for temporary exhibition a large collection of paintings by John Ross Key, mainly landscapes of the near-by States but including a number of interesting canvases representing colonial mansions of Washington and near-by Maryland and Virginia. These latter paintings have much sentimental interest aside from the subjects represented, being the handiwork of the grandson of Francis Scott Key, the author of our Star-Spangled Banner. At the close of the exhibition the owner, Mrs. Ellenore Dutcher Key, was permitted to continue the exhibition for several months beyond the stipulated period, and the collection is still held in reserve at the close of the fiscal year 1928.

REINSTALLATION OF COLLECTIONS

At the close of the loan exhibition season in July, reinstallation of the gallery collections, largely in storage, was taken up and given very careful attention, so that the appearance of the gallery to-day is more satisfactory and the collections more fully representative than

at any previous period. Paintings of the highest order of merit were chosen, and overcrowding was avoided. Many works are, however, held in reserve, but all of these are hung where they may be seen to advantage by visitors desiring to examine them.

LABELING OF COLLECTIONS

Upward of 100 metal labels have been engraved and attached to the frames of the paintings to which they belong. Aside from these labels, all necessarily of small size, and limited to the simplest essentials of record, framed labels giving fuller data are attached to the background in close proximity to the pictures.

CARE OF COLLECTIONS

Requisite care has been given to all paintings with respect to repair, restoration, varnishing, and glazing, there remaining unglazed only four works which are of such large size that glass can not be introduced. Three paintings requiring expert treatment, Man Wearing a Large Hat, by Rembrandt; portraits of Lord Abercorn, by Lawrence, and of Viscount Hill, by Reynolds, were intrusted to the expert restorer of old masters, Mr. H. E. Thompson, of the Boston Museum of Fine Arts, and have been returned to the gallery in an entirely satisfactory state.

ART WORKS RECEIVED DURING THE YEAR

Accessions of art works by the Smithsonian Institution, subject to transfer to the National Gallery on approval of the advisory committee of the gallery commission, are as follows:

Portrait of Admiral Samuel Francis Du Pont (1803–1865) by Daniel Huntington, P. N. A. (1816–1906); bequest of Mrs. May Du Pont Saulsbury, for the National Portrait Gallery.

A painting entitled "Grand Canyon of the Yellowstone," by Thomas Moran, N. A. (1837–1926); gift of Mr. George Dupont Pratt, of New York City.

A painting by Belmore Browne (1880–), entitled "The Chief's Canoe," purchased from the Henry Ward Ranger fund by the council of the National Academy of Design, trustees of the fund, and assigned to the gallery.

Thirty-six pieces of porcelain including pate-sur-pate by Solon and his pupil, A. Birks; Old Worcester ware; Hall porcelain; Meissen; and Capo di Monto, Doccia, and other Italian porcelains. Gift of Mrs. Alfred Duane Pell as an addition to the Alfred Duane Pell collection.

Miniature painting of Mrs. Harriet Lane Johnston by John Henry Brown (1818–1891); bequest of Miss May S. Kennedy, cousin of Mrs. Johnston, as an addition to the Harriet Lane Johnston collection, "said painting (according to the terms of acceptance) * * * to be placed in the case beside the miniature of President Buchanan and there permanently exhibited, and in case it shall not be so exhibited, it shall revert to the members of the family of May S. Kennedy, in accordance with the terms of her said will."

Thirteen specimens of modern Japanese cloisonné, and a series of nine small vases illustrating the stages of manufacture, with the tools and materials used in the manufacture of cloisonné, all by Yoshichika, of Tokyo, Japan; presented by Seth B., jr., and Thomas Dudley Robinson, of New York City.

Medallion portrait in bronze of Dr. Charles W. Elliot, by W. Clark Noble; gift of the sculptor.

A painting, entitled "The Abbess," by Govaert Camphuysen (1624–1674); bequest of Mrs. Emily H. Edrington.

LOANS ACCEPTED BY THE GALLERY

Portrait of Lady Evelyn Cook, by John Hoppner, N. A. (1758–1810); lent by Mrs. Arthur Lee, of Washington, D. C.

A painting entitled "A Farnese Investiture," attributed to Titian (1477–1576); lent by Mrs. Estelle Bakewell-Green, Norwood, Pa.

A painting entitled "The Immaculate Conception with the Mirror," by Bartolomé Estéban Murillo (1617–1682); lent by Mr. De Witt V. Hutchins, Riverside, Calif.

Portraits of Fisher Ames, by Gilbert Stuart, and Alexander Hamilton, by John Trumbull; lent by Mr. George Cabot Lodge, of Washington, D. C.

A painting entitled "The Lido, Venice," by H. Corrodi, Rome (1844–1905); lent by Mr. Arthur T. Brice.

Portrait of Dr. Charles G. Abbot, Secretary of the Smithsonian Institution, 1928– , by S. L. Huntley; lent by Doctor Abbot.

Portrait of Henry, Prince of Wales (or Prince Charles), by C. Janssens van Ceulen (1664); lent by Mr. and Mrs. Marshall Langhorne, Washington, D. C.

DISTRIBUTIONS

Paintings lent to the gallery have been withdrawn by their owners as follows:

Portrait of Thomas Amory, of Boston, by Gilbert Stuart; withdrawn by Miss Helen Amory Ernst.

Twenty old masters intrusted to the gallery in 1924 by Mrs. Ralph Cross Johnson for temporary care and display; withdrawn by her

daughter, Mrs. Marshall Langhorne, as follows: Portrait of the Duke of Sussex, by Sir William Beechey; View of St. Paul's and Black Friar's Bridge, by Calcott; Large Landscape, Dedham Vale, and Small Landscape, Heavy Clouds, by Constable; Portrait of Henry, Prince of Wales (or Charles), by Janssens; Portrait of Ruben's Wife, by Jordaens; Self Portrait, by Lawrence; Festive Scene, by Jan Molenaer; Portrait of a Man, by Raeburn; Portrait of Richard Brinsley Sheridan, Portrait of Lord Lifford, Portrait of Mrs. Lloyd, and Portrait of Lord Roth, by Reynolds; Interior of Kings College Chapel, Oxford, by David Roberts; Marine, Approaching Storm, by Stanfield; Dutch Landscape with figures, by Van Strij; Italian Landscape, Classical Landscape, and Small Landscape, by Richard Wilson; Small Seascape, by Guardi.

Fourteen paintings by British and Dutch masters, lent by Henry Cleveland Perkins, Esq., in 1922, withdrawn by the heirs of Mr. Perkins, as follows: Portrait of a Man, by Sir William Beechey; Portrait of a Boy, by John Hoppner; Cottage Scene, by Ladbrooke; Portrait of Henry, First Earl Mulgrave, by Sir Thomas Lawrence; Portrait of a Dutch Lady, by Michael Janson Mierevelt; Portrait of a Girl, by John Opie; Portrait of Frances, Countess of Clermont, by Sir Joshua Reynolds; The Windmill, by Salomon Ruysdael; two Studies of Ruins, and a Landscape, by Richard Wilson; Landscape, by an Unknown Artist; Madonna and Child, attributed to Van Dyck; Portrait of Dutch Lady, by Jan Victoors.

The John H. McFadden collection of 43 British masters, received by the gallery in July, 1922; withdrawn by the trustees of the collection to be transferred to its permanent home in the Philadelphia Museum of Art. The list follows: A Coast Scene, Normandy, by Richard Parks Bonington; The Lock, Hampstead Heath, Storm Coming Up and The Dell in Helmingham Park, by John Constable; Going to the Hayfield, 1849, by David Cox; Blacksmith Shop, near Hingham, Norfolk, and Woody Landscape, at Colney, by John Crome; Henrietta, Lady Rodney, and A Classical Landscape, by Thomas Gainsborough; The Misses Leader, The Leader Children, and Mrs. Weddell and Children, by George Henry Harlow; The Assembly at Wanstead House and The Fountaine Family, by William Hogarth; Mrs. Hoppner, by John Hoppner; Miss West (afterwards Mrs. William Woodgate), by Sir Thomas Lawrence; The Refuge (or The Storm), 1853, by John Linnell, sr.; Old Coaching Days, the Fruits of Early Industry, and The Happy Cottagers, by George Morland; Lady Belhaven, Master Thomas Bissland, Master John Campbell of Saddell, Col. Charles Christie, Lady Elibank, Mr. Lawrie, of Woodlea, Castle Douglas, Alexander Shaw, and Portrait of a Gentleman, by Sir Henry Raeburn; Master Bunbury and The

Right Hon. Edmund P. Burke, M. P., by Sir Joshua Reynolds; Mrs. Crouch, Mrs. De Crespigny, Mrs. Finch, Lady Grantham, Lady Hamilton (study head), Mrs. Tickell, Rev. John Wesley, and Little Bo-Peep, by George Romney; Landscape with Cattle, by James Stark; Laborers—The Brick Cart, 1767, by George Stubbs; Burning of the Houses of Parliament, by J. M. W. Turner; Sir Walter Scott, Bart., by Sir John Watson-Gordon; View on the Thames, by Richard Wilson.

Five paintings by French masters, withdrawn by the Hon. and Mrs. Louis A. Frothingham; The Lake (panel) and Twilight on the River Oise, by C. F. Daubigny; The Little Marauders (panel) and Group of Dogs (Fox Hounds) (panel), by Narcisse Diaz; The Setting Sun (canvas), by J. B. C. Corot.

Mention should be made here of the privilege granted by the gallery to the sculptor Moses W. Dykaar, who has been permitted to temporarily occupy room 29 in the National Museum, which is assigned to the gallery as a studio and workroom.

MISCELLANEOUS

The wall coverings of the gallery, the background for the paintings and other art works, are a consideration of first importance. The burlaps applied to the walls six years ago gradually faded to a golden brown, giving a rich effect to the halls, but later changed to a dull brown so somber that it was removed and replaced in part by burlaps of a light-green tone, a little too positive but contrasting agreeably with the warm tones of the paintings.

A number of burlap-covered screens for gallery use, a prime necessity in accommodating overflow of exhibits, were added to the already large supply. Four easels required for the display of paintings of special note were added, besides one exhibition case of the gem type, eight mahogany settees, and four pedestals for the installation of portrait busts. The gallery to-day is not crowded as heretofore and presents a more finished and restful appearance than at any previous date. Oil paintings, 337 in number, and 82 drawings in various mediums by French artists of note are shown to good advantage on folding screens in the south room, and 70 works worthy of a place in the gallery are held in reserve to be utilized as opportunity occurs.

LIBRARY

The gallery library has added by gift, purchase, and subscription 1,096 numbers to its upward of 1,500 volumes, pamphlets, and periodicals, and 12 water-color paintings by W. H. Holmes, gift of the artist.

It was found possible to enlist the services of Miss Helen V. Barnes, junior librarian, for a period of two months, to assist in the Smithsonian library as a return for work done in that library for the gallery.

PUBLICATIONS

HOLMES, W. H. Report on the National Gallery of Art for the year ending June 30, 1927. Appendix 2, report of the Secretary of the Smithsonian Institution for the year ending June 30, 1927, pp. 53–61.

——— The National Gallery and the Scope and Functions of an Art Museum. No. 5 of the series under Topic 14—Arts, Topical Survey of the Government. United States Daily, Washington, July 17, 1927, Vol. II, No. 106.

Catalogue of A Collection of Portraits by Bernhard Österman, Member of the Royal Swedish Academy of Arts, on view in the National Gallery, Natural History Building, United States National Museum, January 10 to January 24, 1928. Washington, 1928, pp. 1–4; 6 illustrations.

Catalogue of a collection of paintings by contemporary British artists on view in the National Gallery, Natural History Building, United States National Museum, March 5 through April 1, 1928. Washington, 1928, pp. 1–8.

Respectfully submitted.

W. H. HOLMES, *Director*.

Dr. CHARLES G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 3

REPORT ON THE FREER GALLERY OF ART

SIR: I have the honor to submit the eighth annual report on the Freer Gallery of Art for the year ending June 30, 1928:

THE COLLECTIONS

Additions to the collections by purchase are as follows:

POTTERY

28.1. Persian, thirteenth century. Rhages. A large jar, with bands of ornament in bold relief. Dark blue glaze with traces of red painting and gilding. A fine specimen of great significance.

28.2. Persian, twelfth-thirteenth century. Rhages. A goblet, with a painted decoration over a white enamel glaze. The colors are red, blue, grayish-yellow, and light green.

PORCELAIN

28.3. Chinese, early eighteenth century. A shallow bowl with a floral decoration painted in enamels over a white glaze. Mark: Yung Chêng in blue enamel.

28.4. Chinese, early eighteenth century. A shallow bowl, covered by a white glaze inside and a light green glaze outside. The floral decoration is painted in enamels over glaze. Mark: Yung Chêng in blue enamel.

28.5. Chinese, early eighteenth century. A small shallow bowl, covered by a white glaze inside and a rose pink glaze outside. The decoration of bamboo is in two tones of green enamel, inlaid in the glaze. Mark: Yung Chêng in blue enamel.

PAINTINGS

28.6. Persian, late thirteenth century. Abbasid School.

28.7. Two leaves from a ms. book, probably a Manāfi-al-Hayawān. Each page bears a painting of birds and foliage, rendered in water colors and gold.

28.8. Persian, sixteenth-seventeenth century. Turkish School. A battle scene, with mounted warriors, foot soldiers with shields, and a phalanx of chariots. It is rendered in pale colors and gold on a long strip inlaid in a page of manuscript.

28.9. Persian, early sixteenth century. Bukhara School. A portrait of a youthful prince, standing. It is painted in opaque white and green pigment and gold on a ground of pale green.

28.10. Persian, early seventeenth century. Rizā 'Abbāsī School. A youth kneeling and holding out a wine cup. It is painted in black outline with areas of color, and slight gold.

28.11. Persian, early fifteenth century. Timurid period. A battle scene, the siege of a fortress, painted in colors and gold; an illustration in a page of manuscript.

The work of the care and preservation of objects in the collection, which goes forward year by year, has this year included the remounting of four Japanese screens, in addition to completing the work on Japanese screen 01.173, which was begun in the spring of 1927. Twenty-two paintings in the American section have been put in condition. Changes in exhibition during the year have involved 168 different objects, itemized as follows:

63 Whistler etchings.
40 Whistler and other oil paintings.
11 Japanese screens.
6 Japanese lacquer and sculpture.
7 Japanese panels.
4 Chinese pottery.
28 Near Eastern paintings.
1 Indian sculpture.
6 Near Eastern pottery.
2 Siamese sculptures.

Two hundred and twenty-four objects have been submitted for an expert opinion upon them, or for translation of their oriental inscriptions. Thirty-four other translations of inscriptions have been made from photographs submitted to the curator.

Additions to the library include 26 volumes, 28 periodicals, and 59 pamphlets. The Chinese library of the eminent oriental scholar, the late William Woodville Rockhill, which was presented by Mrs. Rockhill to the Smithsonian Institution in the autumn of 1927 and deposited in the Freer Gallery, forms an important addition to the Chinese section of the library. The Rockhill collection comprises 1,100 volumes, ranging in date of publication from 1659 to 1913. A list of the new accessions accompanies this report as Appendix A (not printed).

The books of the field staff comprise a separate and movable unit of the general reference library and are at present installed at the gallery. The total number of volumes in this branch is 661; unbound periodicals, 134; pamphlets, 439; catalogues, 36; and bulletins, 9. Thirty-six volumes have been added during the current year. A complete list of books in the field library accompanies this report as Part II, Appendix A (not printed).

As noted in the report of last year, the demand for photographs by special students and others is constantly increasing the store of negatives. The total number of these is now 1,491, in addition to 829 negatives of Biblical MSS. A certain number of prints from these negatives are always kept in stock to meet the popular demand;

others can be obtained upon order. The total number of sales of reproductions are as follows: Photographs, 1,089; negatives, 2; a rubbing from a Chinese stone relief, 1; lantern slides, 100; post cards, 2,017. All of the foregoing are sold at their cost prices.

The pamphlets issued by the gallery have been increased by a "List of paintings, pastels, drawings, prints, and copper plates, by and attributed to American and European artists, together with a list of original Whistleriana in the Freer Gallery of Art" (Smithsonian Publ. No. 2963), dated March 20, 1928. Sales of gallery publications were as follows:

F. G. A. Pamphlets		319
Synopsis of History		306
Gallery books:		
Gallery VIII	22	
Gallery IX	28	
Gallery X	20	
Gallery XI	16	
Gallery XII	173	
		259
Outline of Study:		
Course I		28
Course II		13
List of paintings, pastels, etc		95
Floor plans		11

THE BUILDING

The shop has been constantly occupied during the year with the making of necessary stands, frames, and cases, general repair work, and the fitting up of two additional workrooms, namely, an office for the field staff and a room for operating the mimeograph and photograph press. A detailed report made by the superintendent is submitted herewith as Appendix C (not printed).

ATTENDANCE

The gallery has been open every day with the exception of Mondays, Christmas Day, and New Year's Day, from 9 until 4.30 o'clock. The total attendance for the year was 111,288. The aggregate Sunday attendance was 32,279, with an average of 620. The week-day attendance amounted to 79,009, with an average of 305. It reached its highest totals in the months between April and October, inclusive. The total number of visitors to the office was 1,218. Of these, 171 came for general information; 48 to study the building and museum methods; 64 to submit objects for examination; 262 to see objects in storage; 221 to study in the library; 80 to see facsimiles of the Washington MSS; 23 to make drawings; 4 to make photographs; and 182 to purchase photographs. Thirty-three classes were given

instruction, four groups were given docent service in the galleries, and two lectures were delivered in the auditorium, as follows:

February 25: Dr. Alfred Salmony, on "Les Problèmes de la Sculpture dans les Indes Orientales." Illustrated.

March 16: Mr. Carl W. Bishop, on "Archeological Research in China." Illustrated. The latter lecture was given under the combined auspices of the Archæological Society of Washington and the Art and Archæology League.

This report marks the close of the fifth year of the Freer Gallery as an institution open to the uses of the public. During these years

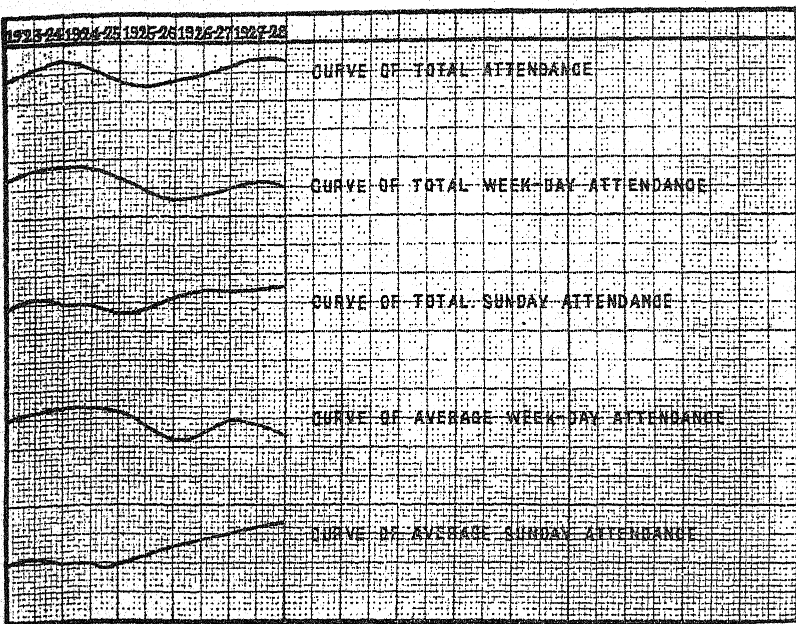


FIGURE 1

the total attendance has been fairly constant, that of the first year reaching 111,942; that of the fifth year, 111,288. The Sunday attendance has noticeably increased, being slightly more than twice as great as week-day attendance during the past year. Figure 1 indicates in graphic form the total and average attendance since the gallery was first opened to the public.

Last winter for the space of a month a record was kept of the average length of time spent by visitors in the exhibition galleries. During the time that this observation was being made the longest visit lasted 2 hours and 45 minutes; the shortest, 11 minutes. Figure 2 indicates the average stay.

While the above records give some indication of the response of the general public to the exhibitions, another survey indicates the demand

made upon the inner resources of the gallery by that smaller section of the public which has an especial interest in the field of art represented in the collections. It is interesting to note the steady growth of this group with its demands analyzed in Figure 3.

FIELD WORK

Owing in part to conditions in China and in part to the large amount of material already secured for study, Mr. C. W. Bishop, associate curator, was, as stated in the report for last year, temporarily recalled to the gallery. He traveled by way of Egypt and the principal western European countries, where he visited collections and sites of importance and held discussions with a number of prominent archeologists. Since his arrival in Washington he has been engaged principally in working up the material collected during his four years and a half in the field.

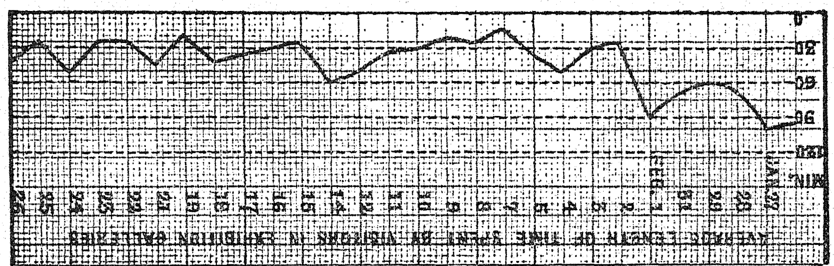


FIGURE 2

Dr. C. Li and Mr. K. Z. Tung, the Chinese members of the field staff, were left in China in order to maintain the contacts already established with various Chinese scientific bodies and to prepare the way for further field work at an early date. In both these tasks they have achieved gratifying success. Negotiations are at present being conducted with the newly-founded bureau of scientific research, an organization whose character and aims correspond somewhat closely to those of the Smithsonian Institution, for cooperation in archeological investigation.

Early in the present summer Doctor Li was called to the gallery to discuss future field work and to complete, with the aid of the facilities now available in Washington, his report on his excavations in southwestern Shansi Province. He plans, upon his return to China, to establish a field station as a semipermanent base of operations, thus permitting the uninterrupted prosecution of excavation for much longer periods.

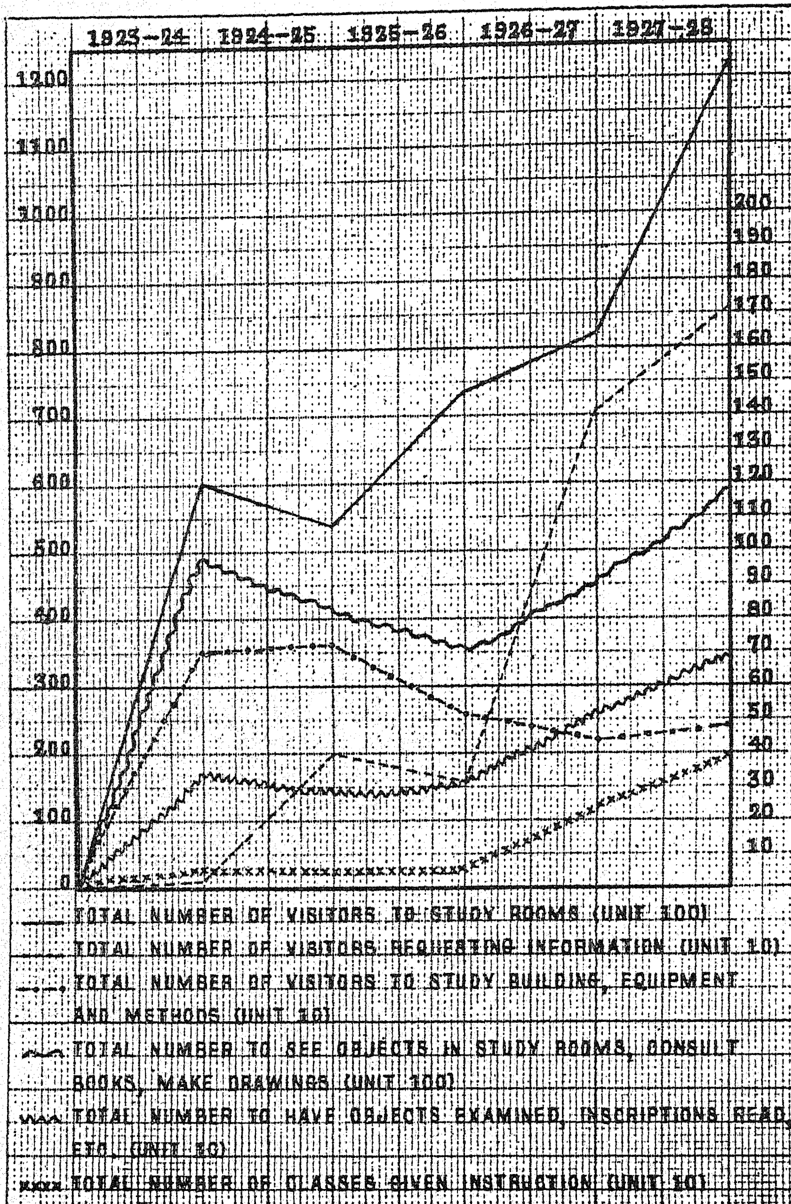

1923-24
1924-25
1925-26
1926-27
1927-28
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
TOTAL NUMBER OF VISITORS TO STUDY ROOMS (UNIT 100)
TOTAL NUMBER OF VISITORS REQUESTING INFORMATION (UNIT 10)
TOTAL NUMBER OF VISITORS TO STUDY BUILDING, EQUIPMENT AND METHODS (UNIT 10)
TOTAL NUMBER TO SEE OBJECTS IN STUDY ROOMS, CONSULT BOOKS, MAKE DRAWINGS (UNIT 100)
TOTAL NUMBER TO HAVE OBJECTS EXAMINED, INSCRIPTIONS READ, ETC. (UNIT 10)
TOTAL NUMBER OF CLASSES GIVEN INSTRUCTION (UNIT 10)

FIGURE 3

A detailed account of the activities of the field staff will be found in Appendix B, herewith submitted (not printed).

PERSONNEL

Mr. Herbert E. Thompson, with his assistant, Mr. Finlayson, worked on the preservation of 22 oil paintings.

Mr. Y. Kinoshita, of the Museum of Fine Arts, Boston, worked at the gallery from January 3 to June 16 on the preservation of oriental paintings.

Miss Christabel E. Hill has been added to the field staff as stenographer.

Mr. A. G. Wenley, field assistant, spent the year in study under Pelliot and Élisséeff, in Paris.

Dr. Chi Li, of the field staff, reported at the gallery on May 26 for a stay of two months.

Respectfully submitted.

J. E. Lodge,
Curator, Freer Gallery of Art.

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

24034—29——6

APPENDIX 4

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY

SIR: The following report on the field researches, office work, and other operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1928, is herewith submitted. This work was conducted in accordance with the act of Congress approved February 11, 1927, which contains the following item:

American ethnology: For continuing ethnological researches among the American Indians and the natives of Hawaii, the excavation and preservation of archeologic remains under the direction of the Smithsonian Institution, including necessary employees, the preparation of manuscripts, drawings, and illustrations, the purchase of books and periodicals, and traveling expenses, $58,720, of which amount not to exceed $48,000 may be expended for personal services in the District of Columbia.

Dr. J. Walter Fewkes, chief of the bureau since March 1, 1918, continued to occupy that position until January 15, 1928, when he retired as chief but continued on the staff of the bureau as associate anthropologist.

The general program of the bureau for the entire year has been similar to that of the last fiscal year.

Doctor Fewkes's scientific work has been mainly devoted to the preparation of a report on his excavations at Elden Pueblo, Ariz., made during the summer of 1926.

Dr. John R. Swanton, ethnologist, completed the proof reading of his papers on the Social Organization and Social Usages of the Indians of the Creek Confederacy, the Religious Beliefs and Medical Practices of the Creek Indians, The Culture of the Southeast, and a paper by the late William E. Myer on Trails of the Southeast, all of which have appeared in the forty-second annual report of the bureau, and of a short paper on the Social and Religious Usages of the Chickasaw Indians which is to appear in the forty-fourth annual report. He spent some time in continuing the preparation of a tribal map of aboriginal North America north of Mexico and the text accompanying, and assisted in the preparation for publication of James Mooney's paper on The Aboriginal Population of America North of Mexico, which appeared as volume 80, No. 7, of the Smithsonian Miscellaneous Collections.

Work in connection with the Timucua dictionary, with the help of Miss Tucker, was continued during most of the year. In 1926,

Miss Irene Wright, in the employ of the Florida State Historical Society, discovered a letter in the archives of the Indies at Sevilla written in the Timucua language. Part of the work of preparing this material for publication by the society has been done by Doctor Swanton, and in the same volume an earlier letter, discovered and published by Buckingham Smith is to be included. Although this publication is being done outside, it will furnish in more convenient and reliable form all of the known material which we have not yet drawn upon for the dictionary, some scattered words alone excepted. Doctor Swanton has been called upon for an unusual amount of advisory and other special work during the past year.

From July 1 to 22 Dr. Truman Michelson, ethnologist, continued ethnological and linguistic work among the Sauk and Fox of Iowa. From the latter part of July to the end of August he was engaged in work on the Northern Arapaho, devoting his time mainly to linguistics, and was able to unravel a number of complex phonetic shifts whereby a larger proportion of Algonquian elements in the language were made more certain than hitherto suspected. He also took physical measurements of a number of Arapaho and Shoshoni Indians. As far as the latter is concerned, the cephalic index of his series agrees closely with that obtained under the direction of Doctor Boas more than 20 years ago. After his return to Washington, September 1, he corrected the proofs of his notes on the buffalo-head dance of the thunder gens of the Fox Indians, which will appear as Bulletin 87 of the bureau.

Doctor Michelson submitted for publication a work entitled "Observations on the Thunder Dance of the Bear Gens of the Fox Indians," which is to be issued as Bulletin 89 of the bureau. He has also submitted a manuscript designated "Sketch of the Buffalo Dance of the Bear Gens of the Fox Indians." He worked out a complete translation of a syllabic text supplementary to his paper in the fortieth annual report. A number of technical papers have been prepared by Doctor Michelson and published in various scientific journals. Doctor Michelson from time to time has furnished data to answer official correspondence.

Mr. J. P. Harrington, ethnologist, spent the year in a study of the Mission Indians of the Santa Barbara region of California and of the Taos Tribe of north-central New Mexico.

Leaving for the field in the fall of 1927, Mr. Harrington resumed his field studies at Santa Barbara with great success, securing a mass of important linguistic information from the last few aged survivors of the proud and highly cultured people which only a few decades ago thickly populated the islands and mainland coasts of the Santa Barbara region. The material covered the entire range of knowledge of the informants and included difficult translations into

the Chumashan. These translations now include an almost exhaustive study of the earlier period of Chumashan history. The grammatical material was all perfectly heard and reaches into every corner of phonetic phenomena and grammatical construction. The work contains a new and exhaustive study of the early voyages, proving, among other points that will have great popular interest, that Cabrillo was the discoverer of Monterrey. It also contains translations made by Mr. Harrington of the diaries of the early land expeditions, throwing new light on hitherto dark chapters of the earliest history of Alta California, since this history is here for the first time dealt with from the Indian viewpoint. In this work Mr. Harrington has cooperated with Fr. Zephyrin Engelhardt, custodian of the Santa Barbara Mission archives, and with Dr. H. E. Bolton and other friends at the Bancroft Library of the University of California.

Returning to Washington in March, Mr. Harrington elaborated his recent notes and prepared his Taos material for publication. This consists of a thorough presentation of the documents of Taos Indian history, all of them worked through afresh and provided with new original translations by Mr. Harrington, a presentation of Taos ethnology, and a comprehensive vocabulary of the Taos language, which, as Mr. Harrington has recently pointed out, has close genetic relationship with the Kiowa language.

At the beginning of the fiscal year 1928 Mr. J. N. B. Hewitt, ethnologist, undertook a detailed study and interpretation of certain Onondaga Iroquoian texts recorded by him in former years relating to the wind or air gods, who are in fact disease gods of Iroquoian mythic thought. These texts are Delphic in their brevity, and so are most difficult to interpret and to correlate. They are only brief myths, most of the details of which have been forgotten, and so the mode of telling them has become oracular.

Mr. Hewitt read the galley proof of his paper in the forty-third annual report of the bureau, Iroquoian Cosmology, Second Part. Severe illness during the early winter delayed this work, but upon partial recovery he completed this task and also the final reading in page proofs.

Mr. Hewitt also edited Mr. Edwin Thompson Denig's manuscript, Report on the Indian Tribes of the Upper Missouri to the Hon. Isaac H. Stevens, Governor of Washington Territory. He added an introduction to the report, with a brief biography of the author.

As the representative of the Smithsonian Institution on the United States Geographic Board, Mr. Hewitt attended the meetings of the board and of the executive committee of that board, of which he is also a member.

As custodian of the bureau manuscripts, Mr. Hewitt reports the continuation of the work of recataloguing the manuscript material

and the phonograph music records belonging to the archives. Miss M. W. Tucker typed the cards and stored the material, and also catalogued 250 cylinders of the Osage Indian songs and rituals. These were verified by Doctor LaFlesche with the use of the phonograph, and are therefore authentic. Mr. Harrington has also turned over his collection of 100 cylinders. Miss Densmore has, to date, a total of 1,697 cylinders listed and filed.

There are now 3,079 manuscripts in the archives, and about 626 phonograph records, in addition to those of Miss Densmore.

On May 18, 1928, Mr. Hewitt left Washington to continue his studies among the Iroquoian and Chippewa tribes in Canada. He visited the Chippewa at Garden River to revise certain cosmic texts acquired in 1900 from Mr. John Miscogeon, of Bay View, Mich., and from Mr. George Gabaoosa, of Garden River, in 1921. He also visited the Huron remnant at Loretteville, near the city of Quebec, Canada, to ascertain whether any knowledge of an institution resembling closely the League of the Five Iroquois Tribes formerly extant among the Hurons then dwelling about Lake Simcoe still existed among this remnant of the Hurons. But no remembrance of it was found.

He also visited the Caughnawaga Mohawk living near Montreal, where information regarding the league and its institutions was sought, but he found only a jumble of ideas coming from the old religious thought of the natives, from the so-called Handsome Lake reformation, and from the hazy ideas instilled into them by the missionaries. Here Mr. Hewitt also sought information tending to identify the so-called Seven Nations of Canada, etc., who have recently become a problem for the Canadian Department of Justice and of the law department at Albany, N. Y.

Mr. Hewitt's most fruitful field of research was among the Six Nations of Iroquois living on the Grand River grant not far from Brantford, Canada. Here he undertook the free translation of the historical tradition of the founding of the League of the Five Iroquois Tribes in the closing decades of the sixteenth century, as related by the Mohawk and the Onondaga, which embodies the farewell address of Deganawide, the master mind in the work of establishing that institution. He also revised the seven myths in native Onondaga texts relating to the gods of the air and the wind who control diseases.

He also was fortunate enough to secure the emblem of official authority of the fire keeper of the council of the league to open and to close the sessions of the council.

Mr. Hewitt, as usual, has devoted much time to providing, through careful research, data for replies to the many correspondents of the bureau.

During the fiscal year ended June 30, 1928, Dr. Francis LaFlesche, ethnologist, completed two manuscripts: Wa-sha-be A-thi^{n}, containing 270 pages, and Wa-wa-tho^{n}, or Pipe Ceremony, containing 110 pages. Another manuscript is in the hands of the editor, entitled "The Child-Naming Ritual."

He started a dictionary of the Omaha language, obtaining about 7,000 words with both the Indian and the English meaning and usage. In November he began the compilation of a dictionary of the Osage language. About 20,000 words with their full meanings and usage have been completed.

The month of July, 1927, and the first part of August were spent by Dr. F. H. H. Roberts, jr., archeologist, in the Chaco Canyon, N. Mex., completing the excavation of a late basket-maker site. It was discovered that the latter had been a village consisting of 18 houses, a kiva or circular ceremonial structure; 48 storage bins; and a court. Definite knowledge of the house type was obtained during the progress of these excavations, as well as other information of value concerning one of the lesser known stages in the cultural development of the sedentary, agricultural Indians of the prehistoric Southwest. The work in the Chaco added materially to the information on southwestern archeology.

Two weeks of August were spent in southeastern Utah in a reconnaissance along Montezuma Creek, one of the northern tributaries of the San Juan. The purpose of this reconnaissance was to locate additional late basket-maker sites which might warrant intensive investigation. Despite heavy rains and flooded conditions of the streams, he was able to make his way up Montezuma Creek a distance of 40 miles. Several late basket-maker sites were observed, but in every case the remains were so eroded that it was not deemed advisable to do any excavating. Several ruins were visited which were of interest because they had been noted and described by W. H. Jackson in the Hayden survey report for Colorado and adjacent territory, 1876. Although unique from an architectural standpoint, the ruins belong to the late Mesa Verde era, the period when the pottery characteristic of the large Mesa Verde pueblos and cliff dwellings was in vogue.

At the end of August Doctor Roberts went to Pecos, N. Mex., where he attended the conference of southwestern archeologists and ethnologists held at the Pecos ruins, where the Andover Academy expedition under Dr. A. V. Kidder was completing its extensive investigations of that well-known pueblo. While at the conference he assisted in the drafting of a new outline of the sequence of cultural stages in southwestern prehistoric and early historic development of the sedentary Indian groups.

The first week in September found him at Folsom, N. Mex., where workmen of the Colorado Museum of Natural History, Denver, had uncovered several projectile points in direct association with the bones of an extinct species of bison, *Bison taylori*. Several days were spent in investigating the fossil bed and the surrounding territory. Doctor Roberts was so impressed with the find that he sent for Dr. A. V. Kidder, of the Andover Academy and the Carnegie Institution of Washington, and with him again went carefully over the problem presented. At the conclusion of the investigations Doctor Roberts and Doctor Kidder were convinced that the bones and the projectile points had been deposited in the stratum contemporaneously. He returned to Washington early in October.

The winter was spent in the preparation of a manuscript on the season's work, entitled "Shabikeshchee Village, a Late Basket-Maker Site in the Chaco Canyon, New Mexico." Another manuscript entitled "Recent Archeological Developments in the Vicinity of El Paso, Tex.," was also completed.

In February Doctor Roberts went to Melbourne, Fla., to view, in situ, a projectile point which Dr. J. W. Gidley, of the United States National Museum, had found in a stratum from which he was removing the bones of extinct Pleistocene animals. The projectile point and bones were from the same stratum which in previous work had yielded the crushed skull of a human being. It is around the latter that much anthropological and paleontological discussion has centered during the last two years. Doctor Roberts took advantage of the trip to Melbourne to visit a number of shell heaps and mounds left by some of the earlier Indian inhabitants of the region.

In May, 1928, Doctor Roberts made a reconnaissance along the San Juan River to a point about 10 miles south of Rosa, N. Mex. Returning to Arboles, Colo., a short survey and inspection was made of the ruins and ruin sites along the Piedra River, one of the larger tributaries of the San Juan. As a result of the latter it was determined to excavate a site located on a bluff 100 feet above the river on the east side of the Piedra 15 miles north of Arboles.

The month of June was spent in an intensive investigation of the above site, which proved to be a Pueblo I village. Of the 24 houses excavated, 21 were single-room structures. Of the remaining 3, 2 had been 2-room domiciles, while the third had contained three cell-like rooms. It was found that the structures varied considerably in size, some of them being but 5 to 6 feet square, while others were 25 to 30 feet in length by 6 to 9 feet in width, but all had been constructed in the same manner. In most cases there had been a slight excavation measuring from 6 inches to 1 foot in depth. This pit portion of the dwelling, if the slight excavation may be so called,

was roughly rectangular in shape. At an average distance of 10 inches from each corner a large post had been set in the floor. These four posts appear to have carried at their tops a rectangular framework, which formed the support for the roof and walls. Both the roof and walls had had a framework of small poles, which was covered with adobe plaster averaging 6 inches in thickness. The roof proper seems to have been flat, while the walls had a slight slope due to the fact that the poles which formed them had had their lower ends embedded in the earth around the edges of the shallow pit, while their upper ends leaned against the framework at the tops of the large support posts. In most cases the rooms were entered by means of a small doorway in the center of one of the side walls. One or two of the structures gave the suggestion of a roof entrance. In all cases the doorway seems to have had a large stone slab for a cover.

There seems to have been a definite method of grouping the houses, from four to eight or more of them being grouped in a semicircle around a circular depression. Two of these depressions were excavated and two more were trenched in the hope that they might be found to contain kivas or ceremonial rooms, but in all four cases they were found to be nothing more than pits. It is quite possible that the earth used in making the plaster to cover the wooden framework of the structures was taken out of these pits; possibly the plaster itself was mixed there, while the hole remained to serve as a reservoir for the storing of water. In each case the lower portions of the pits gave distinct evidence of having been filled with water.

Refuse mounds containing burials were found in most cases to lie some distance south or southeast of the house clusters. The burials were of the contracted form, the body being placed in the shallow grave with the knees drawn up to the breast and the lower limbs tightly flexed to the upper. Accompanying each burial were two or three pottery vessels as mortuary offerings.

A good collection of pottery and other specimens was secured from the houses and graves.

An interesting sidelight on the village is that it was destroyed by fire, presumably in the fall or early winter, as practically every vessel found in the structures contained corn, beans, wild cherries, or some other form of vegetal food. It appears that very little of the harvest had been used when through some mischance or other the village was devastated by flames. Two of the inhabitants were trapped in the houses, as the findings of the skeletons on the floor would indicate. In both instances the remaining fragments of bone showed clearly the marks of fire, and there was every evidence to show that the bodies had been consumed in the flames.

SPECIAL RESEARCHES

Research in the music of the American Indians has been carried forward during the past year by Miss Frances Densmore, a collaborator of the bureau. In October, 1927, Miss Densmore visited the Winnebago in Wisconsin, recording songs and interviewing many Indians within a radius of about 20 miles around Black River Falls. Eighty-three songs were recorded, with data concerning their origin and use, and the singers and their environment were photographed. The winter feast (also known as the war-bundle feast) and the buffalo dance received special consideration, as these are distinctively Winnebago ceremonies. Twenty-five winter feast songs were recorded, including those of the night spirit, morning star, sun, bear, and thunderbird bundles. The songs were recorded and information given by men who habitually attend this feast, given annually in Wisconsin and Nebraska. The use of music in the treatment of the sick was found to be similar to that of the Chippewa and, in some respects, to that of other tribes. The principal informant on this subject was John Henry, living at Trempeleau, who recorded the songs used by his grandfather when treating the sick. Additional old healing songs included those formerly used by a Winnebago named Thunder and recorded by his sons. Herb remedies were administered and songs sung to make them effective.

Among the war songs is a group composed by members of the tribe when serving in France with the United States Army during the recent war. These express a high patriotism and are interesting examples of songs composed by several persons in collaboration. This is a phase of musical composition which has been observed among the Sioux and Makah, as well as among Indians of British Columbia. Other classes of recorded Winnebago songs are those of the Heroka (bow and arrow spirits), songs to calm the waves, songs received in dreams, and songs of the moccasin game.

One purpose of the work among the Winnebago was to ascertain whether their songs resembled those of the neighboring Chippewa or the related Sioux. The songs show a distinct resemblance to the Chippewa and to the Menominee. Each tribe has its own songs, and exceedingly old songs of each tribe have been obtained, but there is a general resemblance in the melodic trend.

The study of material obtained at Neah Bay, Wash., and in British Columbia in 1926, as well as Menominee material obtained in 1925, was continued, together with the work on Winnebago songs. Eight manuscripts were submitted with the following titles: "Dance and dream songs of the Makah and Clayoquot Indians"; "Miscellaneous Makah and Clayoquot songs and Makah customs"; "Nitinat war and dance songs and Menominee songs connected with stories

of Manabus, with catalogue numbers of 184 songs"; "Songs of Nitinat medicine men and miscellaneous Nitinat songs, with catalogue numbers of Nitinat songs"; "Songs of Indians living on the Fraser and Thompson Rivers in British Columbia"; "Winnebago songs of the Winter Feast"; "Winnebago songs used in the treatment of the sick"; and "Winnebago war songs, with catalogue numbers of Winnebago songs."

The paper on Makah customs includes a consideration of such topics as the construction of houses and canoes, tools, rope, clothing, fishing, cooking, tatooing, and wedding customs, also methods of making observations of the sun, and beliefs concerning petitions for supernatural help.

Early in June, 1928, Mr. H. Hughes, of Ono, Russell County, Ky., advised the Smithsonian Institution of certain Indian objects recently exhumed from a cave in the bluffs bordering Wolf Creek, a branch of Cumberland River. To examine these objects and the scene of their discovery, Mr. Neil M. Judd, curator of American archeology, United States National Museum, was directed to proceed to Ono.

Accompanied by Mr. Hughes, Mr. Judd called upon the three gentlemen concerned with the discovery of the material in question, examined the specimens, and later visited the shallow cave from which they had been removed. The collection included parts of three skeletons—two adults and an adolescent—a fragment of a buckskin head band with fiber ropes attached, fragments of an olivella shell necklace, a covered basket, and portions of two others. The basket, certainly the most important of the several items, was woven of split reeds; it is about 20 inches long, 8 inches wide, and 8 inches deep, and was provided with a cover of approximately equal size that fitted completely over the container. The basket is doubtless of Cherokee origin; pottery fragments found in the cave tend to confirm this deduction.

Owing to the fact that the site of discovery is only a shallow shelter in a thick stratum of disintegrating shale, it is truly remarkable that these textile fragments should have been so well preserved. Layers of burned clay and ash indicated frequent though intermittent use of the shelter by Indian peoples. Fragments of corncobs, one small red bean, gourd rind, and squash seeds were observed among the shaly deposits covering the narrow floor space.

During the summer and early fall of 1927 archeological investigations for the Bureau of American Ethnology were continued by Mr. H. W. Krieger, curator of ethnology, United States National Museum, in the arid section of the Columbia Basin and in the lower valley of Snake River. During the preceding year the region extending

from the mouth of the Yakima River to the Canadian border was explored. During the season of 1927 exploration of archeological sites was continued from the mouth of the Yakima River to Mosier, Oreg., in the vicinity of The Dalles. At this point an appreciable increase in rainfall and forest growth marks the dividing line between the humid northwest coast and the arid plateau of the interior.

In most essentials the early occupants of the upper plateau possessed a remarkably uniform culture. It was found that the subculture area of north-central Oregon appears to be distinguished by the excellent chipping of weapon points and tools from obsidian, jasper, agate, and chalcedony. The subarea of The Dalles and Miller Island, the so-called "Dalles culture," is characterized to a greater degree than is the subarea of north-central Oregon by realistically shaped animal and human figurines executed in stone and wood and appearing on wooden combs, stone pestle heads, stone bowls, and as stone plaques. The subarea of The Dalles is also unique in the possession of a lozenge or ovoid-shape stone knife with beveled lateral surfaces shaped by rubbing. This type of knife was found in abundance at Lyle, Wash. In the Snake River Valley a form of bone or horn knife supplants the knife of chipped stone which prevails elsewhere in the Columbia Basin, except in the areas mentioned.

Materials used as tools or as media on which to execute art designs are characteristic of very restricted localities and vary in many instances from village to village. The distinctions are the more clear cut the more ancient the site and the more free the area from the influence of contiguous culture areas.

At Page, Wash., on the Snake River, about 20 miles from Pasco, were noted definite departures from the general type of archeological remains characteristic of the sites along the Columbia River. No copper ornaments or other objects of metal were found; nor were any objects uncovered, other than dentalium shell, that might indicate intercourse with British Columbia or with the tribes of the lower Columbia. Bone knives and scrapers here displaced those of chipped stone; weaving implements and perforators were of antler or bone instead of rubbed stone as on the Columbia. Pairs of sandstone arrow-shaft rasps; fine-grained, grooved stone polishers; basketry fragments, showing styles of false embroidery, lattice weave, and simple coiling and twining; ovoid stone clubs; and burials either with red paint or of the usual cremation group type—all these characteristics indicate a subculture area transitional between the Shoshoni on the east and south and the Shahaptian tribes of the middle Columbia Basin.

The type of early culture that existed within the arid sections of the Columbia Basin has become definitely established. Many of the connecting culture and trade relationships are now known. The re-

lationship with the Shoshoni and with other cultures on the south, those of the basket maker and the pueblo, is not yet clearly defined. Further research along the Snake River and its tributaries in southern Idaho, northern Utah, and Nevada will no doubt bring out additional evidence of relationships with the preagricultural peoples of the Southwest.

Mr. Henry B. Collins, jr., assistant curator of ethnology, and Mr. T. Dale Stewart, of the division of physical anthropology, United States National Museum, were detailed to conduct field work along the coast of western Alaska, including the island of Nunivak, for the purpose of observing these people, their manner of life, and their physical type, as well as to collect skeletal and cultural material from inhabited, and abandoned villages. From the standpoint of the anthropologist, the section of Alaska from Bristol Bay northward along the coast to the mouth of the Yukon is one of much interest, for here dwell the most primitive group of Eskimo to be found in all of Alaska. The work was conducted under the auspices of the Bureau of American Ethnology, the United States National Museum, the American Association for the Advancement of Science, and the American Council of Learned Societies.

Transportation to Nunivak Island was obtained on the U. S. S. *Boxer*, through the courtesy of the Federal Bureau of Education, which operates this boat in the interest of the native schools it maintains throughout Alaska. The *Boxer* stopped at Unalaska, Akutan, and Ugashik on the Aleutian Islands and the Alaska Peninsula, and later at Kanakanak on the upper part of Bristol Bay.

Leaving Bristol Bay, the journey was continued northward along the coast, stopping at Kukukak, Togiak, Mumtrack, and Tanunuk. The Eskimo here live in small villages, usually along the coast near the mouth of a stream. They subsist principally on fish, seal, and birds, together with berries and a few other native plants. The most important item of their clothing is the parka, a long coatlike garment made of feathers or fur. Their dwellings are semisubterranean, consisting of a square or octagonal excavation from 1 to 3 feet deep, with walls and roof built up of successive tiers of driftwood logs, for there is no timber anywhere along the coast north of Bristol Bay. The outside is completely covered with sod.

For winter travel the Eskimo use sleds and dog teams, while in summer most of their journeys are made in the kayak, the ingeniously made skin boat so typical of the Eskimo everywhere.

On June 21 Mr. Collins and Mr. Stewart landed at Nash Harbor on the northwestern end of Nunivak Island, 48 days after leaving Seattle. Here at the small native village of Kligachimiuny is located the school of the Bureau of Education. Nunivak Island is 70 miles

long and about 45 miles wide, but there are no dependable charts of its shores except for two restricted localities.

While very little was definitely known of them, the Nunivak Eskimo have long been regarded as the most primitive in this remote region. This was found to be true. Women were found still wearing the lip, ear, and nose ornaments of beads and walrus ivory that were given up years ago by the other Eskimo of western Alaska. The elaborate observances and ceremonies relating to the hunting of the seal, and their social and religious life in general, furnish additional evidence of the extreme conservatism of these people.

The first work accomplished at Nash Harbor was the taking of measurements and physiological observations on the natives. Much of the western end of the island was explored on foot, bones and ethnological material being collected from several deserted villages and finally from the village at Nash Harbor. After completion of the work on the western end of the island, camp was removed to Amolowikimiut, a native village at Camp Etolin, some 30 miles to the east.

In August the party left Nunivak Island, Mr. Stewart going to St. Michael with the trader from Tanunuk village, Nelson Island, while Mr. Collins stopped at Hooper Bay, an Eskimo village on the mainland between Nunivak and the Yukon, where additional collections were secured. From St. Michael the outward trip was made up the Yukon to Nenana, and thence to the coast to Seward, affording an opportunity to observe the Eskimo along the lower Yukon and later the Tinné Indians farther up the river.

EDITORIAL WORK AND PUBLICATIONS

The editing of the publications of the bureau was continued through the year by Mr. Stanley Searles, editor, assisted by Mrs. Frances S. Nichols, editorial assistant. The status of the publications is presented in the following summary.

PUBLICATIONS ISSUED

Forty-second Annual Report. Accompanying papers: Social Organization and Social Usages of the Indians of the Creek Confederacy (Swanton); Religious Beliefs and Medical Practices of the Creek Indians (Swanton); Aboriginal Culture of the Southeast (Swanton); Indian Trails of the Southeast (Myer). 900 pp. 17 pls. 108 figs.

Bulletin 85. Contributions to Fox Ethnology (Michelson). 168 pp.

PUBLICATIONS IN PRESS

Forty-first Annual Report. Accompanying papers: Coiled Basketry in British Columbia and Surrounding Region (Boas, assisted by Haeberlin, Roberts, and Teit); Two Prehistoric Villages in Middle Tennessee (Myer).

Forty-third Annual Report. Accompanying papers: The Osage Tribe: Two Versions of the Child-naming Rite (La Flesche); Wawenock Myth Texts from Maine (Speck); Native Tribes and Dialects of Connecticut (Speck); Picuris Children's Stories, With Texts and Songs (Harrington); Iroquoian Cosmology, Part II (Hewitt).

Forty-fourth Annual Report. Accompanying papers: Excavation of the Burton Mound at Santa Barbara, Calif. (Harrington); Social and Religious Usages of the Chickasaw Indians (Swanton); Uses of Plants by the Chippewa Indians (Densmore); Archeological Investigations II (Fowke).

Bulletin 84. A Vocabulary of the Kiowa Language (Harrington).

Bulletin 86. Chippewa Customs (Densmore).

Bulletin 87. Notes on the Buffalo-head Dance of the Thunder Gens of the Fox Indians (Michelson).

Bulletin 88. Myths and Tales of the Southeastern Indians (Swanton).

Bulletin 89. Observations on the Thunder Dance of the Bear Gens of the Fox Indians (Michelson).

Bulletin 90. Papago Music (Densmore).

DISTRIBUTION OF PUBLICATIONS

The distribution of the publications of the bureau has been continued under the charge of Miss Helen Munroe, assisted by Miss Emma B. Powers. Publications were distributed as follows:

Report volumes and separates	1, 450
Bulletins and separates	6, 870
Contributions to North American Ethnology	23
Miscellaneous publications	783
Total	9, 126

There was a decrease of 788 publications distributed, due to the fact that 1 less publication was distributed to the mailing list than in the previous year. The mailing list, after revision during the year, now stands at 1,713 addresses.

ILLUSTRATIONS

Following is a summary of work accomplished in the illustration branch of the bureau under the supervision of Mr. De Lancey Gill, illustrator:

Drawings made (maps, diagrammatic and graphic illustrations)	55
Photographs retouched, lettered, and made ready for engraving	598
Engraved proofs criticized	582
Color prints examined at Government Printing Office	3, 660
Illustrations catalogued for outside publications	350
Photographic negatives	96
Photographic prints	367
Enlargements	2
Development (films)	12
Color print	1

The development and printing of all photographic work was done in the laboratory of the United States National Museum by Dr. A. J. Olmsted in cooperation with the bureau in exchange for work done by Mr. Gill for other branches of the Institution. This arrangement, as in the previous year, has proved eminently satisfactory.

LIBRARY

The reference library has continued under the care of Miss Ella Leary, librarian, assisted by Mr. Thomas Blackwell. The library consists of 27,921 volumes, about 16,177 pamphlets, and several thousand unbound periodicals. During the year 780 books were accessioned, of which 115 were acquired by purchase and 665 by gift and exchange; also 3,980 serials, chiefly the publications of learned societies, were received and recorded, of which only 108 were obtained by purchase, the remainder being received through exchange. A considerable amount of time was given to preparing bibliographic lists for correspondents. Requisition was made on the Library of Congress during the year for an aggregate of 325 volumes for official use. An increasing number of students not connected with the Smithsonian Institution found the library of service in consulting volumes not obtainable in other libraries.

COLLECTIONS

99366. Archeological and human skeletal material collected in Florida by Henry B. Collins, jr., during January and February, 1928. (133 specimens.)

99553. Lots of potsherds collected on the surface of mounds in the vicinity of Greenville, S. C., during the spring of 1927 by Dr. J. Walter Fewkes.

99554. Small archeological collection purchased by the bureau from R. W. Owen, Philadelphia, Pa. (16 specimens.)

99953. Archeological and human skeletal material collected by H. W. Krieger during the late summer of 1927 in the Columbia and Snake River Valleys. (190 specimens.)

101146. Small collection of archeological specimens from Tennessee secured in the spring of 1928 by Henry B. Collins, jr. (6 specimens.)

101340. Archeological material from two sites in Chaco Canyon, N. Mex., collected during 1927 by Dr. F. H. H. Roberts, jr. (199 specimens.)

101524. Potsherds, stone, and shell objects from a shell mound near Melbourne, Fla., collected by Dr. F. H. H. Roberts, jr. (4 specimens.)

101525. Atlatl spearshafts, sandals, netting, etc., from a cave about 20 miles northeast of El Paso, Tex., collected in May, 1927, by Dr. F. H. H. Roberts, jr. (26 specimens.)

PROPERTY

Office equipment was purchased to the amount of $656.89.

MISCELLANEOUS

Clerical.—The correspondence and other clerical work of the office has been conducted by Miss May S. Clark, clerk to the chief, assisted

by Mr. Anthony W. Wilding, stenographer. Miss Mae W. Tucker, stenographer, continued to assist Dr. John R. Swanton in compiling a Timucua dictionary. She also classified and catalogued 2,323 musical records in the possession of the bureau. Mrs. Frances S. Nichols assisted the editor.

Personnel.—Dr. J. Walter Fewkes retired as chief of the bureau January 15, 1928, but continued on the staff of the bureau as associate anthropologist.

Respectfully submitted.

H. W. Dorsey,
Chief Clerk, Smithsonian Institution.

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 5

REPORT ON THE INTERNATIONAL EXCHANGES

Sir: I have the honor to submit the following report on the operations of the International Exchange Service during the fiscal year ending June 30, 1928:

An appropriation was made by Congress for the support of the system of international exchanges between the United States and foreign countries under the direction of the Smithsonian Institution for the fiscal year 1928 of $46,855, an increase of $595 over the appropriation for the preceding year. This increase in the amount made available for the service was to enable the Institution to advance to the next step in their respective grades such of the exchange employees as were eligible for promotion. In addition to the above, $300 was allotted for printing and binding. The repayments from departmental and other establishments aggregated $5,083.14, making the total resources available for exchange purposes during the year, $52,238.14.

The total number of packages passing through the service was 542,223, a decrease from the number for the preceding year of 48,656. This falling off in the number of packages handled was expected. However, it does not signify that the normal work of the office has slackened to any extent, as the number of packages passing through the service during the preceding fiscal year was the largest since its organization in 1850—the increase being over a hundred thousand packages, while the annual increase usually averages five or ten thousand. The increase in that year was due in great measure, as was explained in last year's report, to the action of the Department of Agriculture in turning over to the exchange office large numbers of small packages for distribution abroad that it formerly transmitted through the mails. That department later discontinued sending the material in question to the Institution.

The total weight of the packages was 594,121 pounds—a gain of 40,996 over the weight of those handled during the preceding twelve months.

The number and weight of the packages of different classes are given in the following table:

	Packages		Weight	
	Sent	Received	Sent	Received
			Pounds	*Pounds*
United States parliamentary documents sent abroad	219, 968		99, 653	
Publications received in return for parliamentary documents		6, 320		23, 693
United States departmental documents sent abroad	153, 373		163, 046	
Publications received in return for departmental documents		5, 560		23, 002
Miscellaneous scientific and literary publications sent abroad	113, 448		196, 546	
Miscellaneous scientific and literary publications received from abroad for distribution in the United States		43, 554		88, 181
Total	486, 789	55, 434	459, 245	134, 876
Grand total	542, 223		594, 121	

In a letter to the American legation in Peking regarding the interchange of governmental documents between China and the United States the Metropolitan Library in Peking, which in 1926 was designated by the Chinese Government as the depository library for all official publications of foreign governments received by China through the International Exchange Service, makes the following statement:

Special mention should be made of the monthly consignments of governmental documents received from the Smithsonian Institution. The Metropolitan Library maintains a reference card catalogue containing general and specific information concerning these publications and endeavors to furnish information to inquirers, either in person or by mail, involving the material over which it has custody.

The official publications of the United States forwarded to China previous to 1926 were scattered in different places. The Library of the Foreign Office, Peking; the Library of the Science Society, Nanking; and the Library of the Chamber of Commerce, Shanghai, are the three places where a portion of these publications are kept. It is hoped that these publications will eventually be concentrated in one large library where a complete file is available for reference and research.

The Metropolitan Library further adds in its letter to the legation:

In writing to the Department of State will you be good enough to convey our high appreciation of the efficient service which the Smithsonian Institution has been rendering to the Metropolitan Library.

The Smithsonian occasionally receives letters from its correspondents testifying to the usefulness of the International Exchange Service and expressing appreciation of the help rendered in diffusing knowledge by distributing scientific and literary publications. Among such communications received during the past year was one

from Mr. George S. Godard, Connecticut State librarian. A part of that letter is given below:

> Every time I make a call at your department I am the more impressed with the most important service you and those associated with you in the International Exchange Service are rendering to the several States, institutions, and others scattered throughout the civilized earth.
>
> As a representative of the State of Connecticut in charge of the State, national, and international exchanges of Connecticut, I wish to again express my thanks for the services you have rendered the good State of Connecticut both in forwarding to others and sending to us.

Another correspondent, the Minister of Guatemala, states that:

> It is my privilege to express to the Institution the sincere thanks of the Government of Guatemala for the interest manifested by the useful and abundant material furnished.

As an example of aid rendered by the International Exchange Service in securing publications on some particular subject, a request was received from a correspondent in London for information as to what America has done toward the important subject of enacting laws to provide for compulsory automobile liability insurance, and the Institution succeeded in procuring quite a number of publications on the subject. In acknowledging their receipt, the correspondent wrote in part as follows:

> I have not up to the present time had the opportunity of reading more than a few of the publications sent to me, but I should like to tender you my very sincere thanks for sending me all the reports desired and in addition many other highly interesting articles. I assure you I appreciate your action very much indeed.

There were shipped abroad during the year 2,872 boxes, being an increase of 264 over the number for the preceding year. Of the total number of boxes sent abroad 643 contained full sets of United States official documents for foreign depositories and 2,229 included departmental and other publications for the depositories of partial sets and for miscellaneous correspondents.

Occasionally, as explained in previous reports, it is found more economical to forward packages direct to their destinations by mail than to transmit them in boxes by freight. In addition, quite a number of packages are sent by mail to remote places which can not be reached through the existing agencies. During the year the number of packages thus forwarded was 47,851.

The number of boxes sent to each foreign country during the fiscal year 1928 is given below:

Consignments of exchanges forwarded to foreign countries

Country	Number of boxes	Country	Number of boxes
Albania	4	Latvia	4
Argentina	62	Lithuania	6
Austria	67	Mexico	11
Belgium	71	Netherlands	66
Brazil	48	New South Wales	39
Bulgaria	5	New Zealand	32
British colonies	25	Norway	69
Canada	55	Palestine	69
Chile	29	Peru	23
China	55	Poland	41
Colombia	22	Portugal	21
Costa Rica	21	Queensland	26
Cuba	11	Rumania	14
Czechoslovakia	68	Russia	134
Denmark	54	South Australia	30
Ecuador	2	Spain	37
Egypt	2	Sweden	87
Estonia	17	Switzerland	66
Finland	14	Tasmania	20
France	198	Turkey	4
Germany	357	Union of South Africa	36
Great Britain and Ireland	337	Uruguay	19
Greece	9	Venezuela	15
Hungary	49	Victoria	59
India	68	Western Australia	25
Italy	158	Yugoslavia	18
Jamaica	2		
Japan	91	Total	2, 872

FOREIGN DEPOSITORIES OF UNITED STATES GOVERNMENTAL DOCUMENTS

The number of sets of United States official documents forwarded abroad to certain designated depositories is 105, an increase of 2 during the year—Burma and Bombay having been added to the list of those countries receiving partial sets. The partial set of governmental documents which has been sent to Rumania since 1903 has been increased to a full set.

Shipments of governmental documents to Turkey, which were suspended at the beginning of the World War, have been resumed, the Turkish Government having designated the Ministry of Public Instruction at Angora as the depository.

At the request of the Government of Yugoslavia, the depository of the full set of official documents in that country has been changed from the Ministry of Foreign Affairs to the Ministry of Education at Belgrade.

The depository of governmental publications sent to the Netherlands, at the request of that Government, has been changed from the Library of the Second Chamber of the States General to the Royal Library at The Hague.

The Government of the Commonwealth of Australia, which was temporarily located in Melbourne, has moved into the recently founded city of Canberra. The set of United States governmental documents sent to the Library of the Commonwealth Parliament, therefore, is now being forwarded to that city instead of to Melbourne.

A list of the foreign depositories is given below:

DEPOSITORIES OF FULL SETS

ARGENTINA: Ministerio de Relaciones Exteriores, Buenos Aires.
 BUENOS AIRES: Biblioteca de la Universidad Nacional de La Plata, La Plata. (Depository of the Province of Buenos Aires.)
AUSTRALIA: Library of the Commonwealth Parliament, Canberra.
 NEW SOUTH WALES: Public Library of New South Wales, Sydney.
 QUEENSLAND: Parliamentary Library, Brisbane.
 SOUTH AUSTRALIA: Parliamentary Library, Adelaide.
 TASMANIA: Parliamentary Library, Hobart.
 VICTORIA: Public Library of Victoria, Melbourne.
 WESTERN AUSTRALIA: Public Library of Western Australia, Perth.
AUSTRIA: Bundesamt für Statistik, Schwarzenbergstrasse 5, Vienna I.
BELGIUM: Bibliothèque Royale, Brussels.
BRAZIL: Bibliotheca Nacional, Rio de Janeiro.
CANADA: Library of Parliament, Ottawa.
 MANITOBA: Provincial Library, Winnipeg.
 ONTARIO: Legislative Library, Toronto.
 QUEBEC: Library of the Legislature of the Province of Quebec, Quebec.
CHILE: Biblioteca del Congreso Nacional, Santiago.
CHINA: Metropolitan Library, Pei Hai, Peking.
COLOMBIA: Biblioteca Nacional, Bogotá.
COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.
CUBA: Secretaría de Estado (Asuntos Generales y Canje Internacional), Habana.
CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.
DENMARK: Kongelige Bibliotheket, Copenhagen.
EGYPT: Bureau des Publications, Ministère des Finances, Cairo.
ESTONIA: Riigiraamatukogu (State Library), Reval.
FRANCE: Bibliothèque Nationale, Paris.
 PARIS: Préfecture de la Seine.
GERMANY: Deutsche Reichstags-Bibliothek, Berlin.
 BADEN: Universitäts-Bibliothek, Freiburg. (Depository of the State of Baden.)
 BAVARIA: Staats-Bibliothek, Munich.
 PRUSSIA: Preussische Staatsbibliothek, Berlin, N. W. 7.
 SAXONY: Sächsische Landesbibliothek, Dresden—N. 6
 WURTTEMBERG: Landesbibliothek, Stuttgart.

GREAT BRITAIN:

ENGLAND: British Museum, London.

GLASGOW: City Librarian, Mitchell Library, Glasgow.

LONDON: London School of Economics and Political Science. (Depository of the London County Council.)

GREECE: Bibliothèque Nationale, Athens.

HUNGARY: Hungarian House of Delegates, Budapest.

INDIA: Imperial Library, Calcutta.

IRISH FREE STATE: National Library of Ireland, Dublin.

ITALY: Biblioteca Nazionale Vittorio Emanuele, Rome.

JAPAN: Imperial Library of Japan, Tokyo.

MEXICO: Biblioteca Nacional, Mexico, D. F.

NETHERLANDS: Royal Library, The Hague.

NEW ZEALAND: General Assembly Library, Wellington.

NORTHERN IRELAND: Ministry of Finance, Belfast.

NORWAY: Universitets-Bibliotek, Oslo. (Depository of the Government of Norway.)

PERU: Biblioteca Nacional, Lima.

POLAND: Bibliothèque du Ministère des Affaires Étrangères, Warsaw.

PORTUGAL: Biblioteca Nacional, Lisbon.

RUSSIA: Shipments temporarily suspended.

SPAIN: Servicio del Cambio Internacional de Publicaciones, Cuerpo Facultativo de Archiveros, Bibliotecarios y Arqueólogos, Madrid.

SWEDEN: Kungliga Biblioteket, Stockholm.

SWITZERLAND: Bibliothèque Centrale Fédérale, Berne.

SWITZERLAND: Library of the League of Nations, Geneva.

TURKEY: Ministère de l'Instruction Publique, Angora.

UNION OF SOUTH AFRICA: State Library, Pretoria, Transvaal.

URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.

VENEZUELA: Biblioteca Nacional, Caracas.

YUGOSLAVIA: Ministère de l'Education, Belgrade.

DEPOSITORIES OF PARTIAL SETS

AUSTRIA:

VIENNA: Magistrat der Stadt.

BOLIVIA: Ministerio de Colonización y Agricultura, La Paz.

BRAZIL:

MINAS GERAES: Directoria Geral de Estatistica em Minas, Bello Horizonte, Minas Geraes.

RIO DE JANEIRO: Bibliotheca da Assemblea Legislativa do Estado, Nictheroy.

CANADA:

ALBERTA: Provincial Library, Edmonton.

BRITISH COLUMBIA: Legislative Library, Victoria.

NEW BRUNSWICK: Legislative Library, Fredericton.

NOVA SCOTIA: Provincial Secretary of Nova Scotia, Halifax.

PRINCE EDWARD ISLAND: Legislative Library, Charlottetown.

SASKATCHEWAN: Government Library, Regina.

BRITISH GUIANA: Government Secretary's Office, Georgetown, Demerara.

BULGARIA: Ministère des Affaires Étrangères, Sofia.

CEYLON: Colonial Secretary's Office (Record Department of the Library), Colombo.

DANZIG: Stadtbibliothek, Free City of Danzig.

DOMINICAN REPUBLIC: Biblioteca del Senado, Santo Domingo.

ECUADOR: Biblioteca Nacional, Quito.
FINLAND: Parliamentary Library, Helsingfors.
FRANCE:
ALSACE-LORRAINE: Bibliothèque Universitaire et Régionale de Strasbourg, Strasbourg.
GERMANY:
BREMEN: Senatskommission für Reichs- und Auswärtige Angelegenheiten.
HAMBURG: Senatskommission für Reichs- und Auswärtige Angelegenheiten.
HESSE: Landesbibliothek, Darmstadt.
LÜBECK: President of the Senate.
THURINGIA: Rothenberg-Bibliothek, Landesuniversität, Jena.
GUATEMALA: Secretary of the Government, Guatemala.
HAITI: Secrétaire d'Etat des Relations Extérieures, Port au Prince.
HONDURAS: Secretary of the Government, Tegucigalpa.
ICELAND: National Library, Reykjavik.
INDIA:
BOMBAY: Undersecretary to the Government of Bombay, General Department, Bombay.
BURMA: Secretary to the Government of Burma, Education Department, Rangoon.
MADRAS: Chief Secretary to the Government of Madras, Public Department, Madras.
UNITED PROVINCES OF AGRA AND OUDH: University of Allahabad, Allahabad.
JAMAICA: Colonial Secretary, Kingston.
LATVIA: Bibliothèque d'Etat, Riga.
LIBERIA: Department of State, Monrovia.
LITHUANIA: Ministère des Affaires Étrangères, Kovno.
LOURENÇO MARQUEZ: Government Library, Lourenço Marquez.
MALTA: Minister for the Treasury, Valetta.
NEWFOUNDLAND: Colonial Secretary, St. John's.
NICARAGUA: Superintendente de Archivos Nacionales, Managua.
PANAMA: Secretaría de Relaciones Exteriores, Panama.
PARAGUAY: Seccón Canje Internacional de Publicaciones del Ministerio de Relaciones Exteriores, Estrella 563, Asunción.
RUMANIA: Academia Romana, Bucharest.
SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.
SIAM: Department of Foreign Affairs, Bangkok.
STRAITS SETTLEMENTS: Colonial Secretary, Singapore.

INTERPARLIAMENTARY EXCHANGE OF OFFICIAL JOURNAL

During the year, three additional foreign depositories were added to the list of those receiving the daily issue of the Congressional Record, the depositories being located in Brazil, Irish Free State, and Turkey.

The two chambers of the National Congress of Spain having been superceded by a national assembly with but one chamber, only one copy of the Record is now forwarded to the Spanish Legislature instead of two. The total number of establishments receiving copies of the daily issue of the Congressional Record is 101.

A complete list of the countries now taking part in this exchange is given below:

DEPOSITORIES OF CONGRESSIONAL RECORD

ARGENTINA:
- Biblioteca del Congreso Nacional, Buenos Aires.
- Cámara de Diputados, Oficina de Información Parlamentaria, Buenos Aires.
- Buenos Aires; Biblioteca del Senado de la Provincia de Buenos Aires, La Plata.

AUSTRALIA:
- Library of the Commonwealth Parliament, Canberra.
- New South Wales: Library of Parliament of New South Wales, Sydney.
- Queensland: Chief Secretary's Office, Brisbane.
- Western Australia: Library of Parliament of Western Australia, Perth.

AUSTRIA: Bibliothek des Nationalrates, Vienna I.

BELGIUM: Bibliothèque de la Chambre des Représentants, Brussels.

BOLIVIA: Cámara de Diputados, Congreso Nacional, La Paz.

BRAZIL:
- Bibliotheca do Congresso Nacional, Rio de Janeiro.
- Amazonas: Archivo, Bibliotheca e Imprensa Publica, Manáos.
- Bahia: Governador do Estado de Bahia, São Salvador.
- Espirito Santo: Presidencia do Estado do Espirito Santo, Victoria.
- Sergipe: Director da Imprensa Official, Aracaju, Estado de Sergipe.
- São Paulo: Bibliotheca Publica do Estado de São Paulo, São Paulo.

CANADA:
- Library of Parliament, Ottawa.
- Clerk of the Senate, Houses of Parliament, Ottawa.

CHINA: Metropolitan Library, Pei Hai, Peking.

COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.

CUBA:
- Biblioteca de la Cámara de Representantes, Habana.
- Biblioteca del Senado, Habana.

CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.

DANZIG: Stadtbibliothek, Danzig.

DENMARK: Rigsdagens Bureau, Copenhagen.

DOMINICAN REPUBLIC: Biblioteca del Senado, Santo Domingo.

DUTCH EAST INDIES: Volksraad van Nederlandsch-Indie, Batavia, Java.

EGYPT: Bureau des Publications, Ministère des Finances, Cairo.

ESTONIA: Riigiraamatukogu (State Library), Reval.

FRANCE:
- Bibliothèque de la Chambre des Députés, au Palais Bourbon, Paris
- Bibliothèque du Sénat, au Palais du Luxembourg, Paris.

GERMANY:
- Deutsche Reichstags-Bibliothek, Berlin, N. W. 7.
- Anhalt: Anhaltische Landesbücherei, Dessau.
- Baden: Universitäts-Bibliothek, Heidelberg.
- Braunschweig: Bibliothek des Braunschweigischen Staatsministeriums, Braunschweig.
- Mecklenburg-Schwerin: Staatsministerium, Schwerin.
- Mecklenburg-Strelitz: Finanzdepartement des Staatsministeriums, Neustrelitz.
- Oldenburg: Oldenburgisches Staatsministerium, Oldenburg i. O.

GERMANY—Continued.

Prussia: Bibliothek des Abgeordnetenhauses, Prinz-Albrechtstrasse 5, Berlin, S. W. 11.

Schaumburg-Lippe: Schaumburg-Lippische Landesregierung, Bücheburg.

GIBRALTAR: Gibraltar Garrison Library Committee, Gibraltar.

GREAT BRITAIN: Library of the Foreign Office, London.

GREECE: Library of Parliament, Athens.

GUATEMALA: Archivo General del Gobierno, Guatemala.

HAITI: Secrétaire d'État des Relations Extérieures, Port-au-Prince.

HONDURAS: Biblioteca del Congreso Nacional, Tegucigalpa.

HUNGARY: Bibliothek des Abgeordnetenhauses, Budapest.

INDIA: Legislative Department, Simla.

ITALY:

Biblioteca del Senato del Regno, Rome.

Biblioteca della Camera dei Deputati, Rome.

IRAQ: Chamber of Deputies, Baghdad, Iraq (Mesopotamia).

IRISH FREE STATE: Dail Eireann, Dublin.

LATVIA: Library of the Saeima, Riga.

LIBERIA: Department of State, Monrovia.

MEXICO: Secretaria de la Cámara de Diputados, Mexico, D. F.

Aguascalientes: Gobernador del Estado de Aguascalientes, Aguascalientes.

Campeche: Gobernador del Estado de Campeche, Campeche.

Chihuahua: Gobernador del Estado de Chihuahua, Chihuahua.

Chiapas: Gobernador del Estado de Chiapas, Tuxtla Gutierrez.

Coahuila: Periódico Oficial del Estado de Coahuila, Palacio de Gobierno, Saltillo.

Colima: Gobernador del Estado de Colima, Colima.

Durango: Gobernador Constitucional del Estado de Durango, Durango.

Guanajuato: Secretaría General de Gobierno del Estado, Guanajuato.

Guerrero: Gobernador del Estado de Guerrero, Chilpancingo.

Jalisco: Biblioteca del Estado, Guadalajara.

Lower California: Gobernador del Distrito Norte, Mexicali, B. C., Mexico.

Mexico: Gaceta del Gobierno, Toluca, Mexico.

Michoacán: Secretaría General de Gobierno del Estado de Michoacán, Morelia.

Morelos: Palacio de Gobierno, Cuernavaca.

Nayarit: Gobernador de Nayarit, Tepic.

Nuevo León: Biblioteca del Estado, Monterey.

Oaxaca: Periódico Oficial, Palacio de Gobierno, Oaxaca.

Puebla: Secretario General de Gobierno, Zaragoza.

Queretaro: Secretaría General de Gobierno, Sección de Archivo, Queretaro.

San Luis Potosi: Congreso del Estado, San Luis Potosi.

Sinaloa: Gobernador del Estado de Sinaloa, Culiacan.

Sonora: Gobernador del Estado de Sonora, Hermosillo.

Tabasco: Secretaría General de Gobierno, Sección 3a, Ramo de Prensa, Villahermosa.

Tamaulipas: Secretaría General de Gobierno, Victoria.

Tlaxcala: Secretaría de Gobierno del Estado, Tlaxcala.

Vera Cruz: Gobernador del Estado de Vera Cruz, Departamento de Gobernación y Justicia, Jalapa.

Yucatán: Gobernador del Estado de Yucatán, Mérida, Yucatán.

NEW ZEALAND: General Assembly Library, Wellington.

PERU: Cámara de Diputados, Congreso Nacional, Lima.

NORWAY: Storthingets Bibliothek, Oslo.
POLAND: Ministère des Affaires Etrangères, Warsaw.
PORTUGAL: Biblioteca do Congresso da Republica, Lisbon.
RUMANIA:
Bibliothèque de la Chambre des Députés, Bucharest.
Ministère des Affaires Étrangères, Bucharest.
SPAIN:
Biblioteca de la Asamblea Nacional, Madrid.
Barcelona: Biblioteca de la Comisión Permanente Provincial de Barcelona, Barcelona.
SWITZERLAND:
Bibliothèque de l'Assemblée Fédérale Suisse, Berne.
Library of the League of Nations, Geneva.
SYRIA:
Ministère des Finances de la République Libanaise, Service du Matériel, Beirut.
Governor of the State of Alaouites, Lattaquié.
TURKEY: Turkish Grand National Assembly, Angora.
UNION OF SOUTH AFRICA:
Library of Parliament, Cape Town, Cape of Good Hope.
State Library, Pretoria, Transvaal.
URUGUAY: Biblioteca de la Cámara de Representantes, Montevideo.
VENEZUELA: Cámara de Diputados, Congreso Nacional, Carácas.
YUGOSLAVIA: Library of the Skupshtina, Belgrade.

FOREIGN EXCHANGE AGENCIES

The Italian Office of International Exchanges, which since its organization had been under the direction of the Victor Emanuel National Library in Rome, was during the latter part of the year placed under the ministry of public instruction.

The Dutch Central Scientific Bureau, which for many years conducted the exchange agency for the Netherlands and was under the direction of various scientific organizations, was made, on January 1, 1928, a subdivision of the Federal organization and placed under the direction of the Royal Library at The Hague. Information has been received from the latter to the effect that the name and address of the agency is now International Exchange Bureau of the Netherlands, Royal Library, Kazernestraat, The Hague. A list of the foreign exchange agencies or bureaus is given below:

LIST OF EXCHANGE AGENCIES

ALGERIA, via France.
ANGOLA, via Portugal.
ARGENTINA: Comisión Protectora de Bibliotecas Populares, Calle Córdoba 931, Buenos Aires.
AUSTRIA: Bundesamt für Statistik, Schwarzenbergstrasse 5, Vienna I.
AZORES, via Portugal.
BELGIUM: Service Belge des Echanges Internationaux, Rue des Longs-Chariots, 46, Brussels.

BOLIVIA: Oficina Nacional de Estadistica, La Paz.
BRAZIL: Servicio de Permutações Internacionaes, Bibliotheca Nacional, Rio de Janeiro.
BRITISH COLONIES: Crown Agents for the Colonies, London.
BRITISH GUIANA: Royal Agricultural and Commercial Society, Georgetown.
BRITISH HONDURAS: Colonial Secretary, Belize.
BULGARIA: Institutions Scientifiques de S. M. le Roi de Bulgarie, Sofia.
CANARY ISLANDS, via Spain.
CHILE: Servicio de Canjes Internacionales, Biblioteca Nacional, Santiago.
CHINA: Bureau of International Exchange of Publications, Ministry of Education, Peking.
COLOMBIA: Oficina de Canjes Internacionales y Reparto, Biblioteca Nacional, Bogotá.
COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.
CZECHOSLOVAKIA: Service Tchécoslovaque des Échanges Internationaux, Bibliothèque de l'Assemblée Nationale, Prague 1–79.
DANZIG: Amt für den Internationalen Schriftenaustausch der Freien Stadt Danzig, Stadtbibliothek, Danzig.
DENMARK: Kongelige Danske Videnskabernes Selskab, Copenhagen.
DUTCH GUIANA: Surinaamsche Koloniale Bibliotheek, Paramaribo.
ECUADOR: Ministerio de Relaciones Exteriores, Quito.
EGYPT: Bureau des Publications, Ministère des Finances, Cairo.
ESTONIA: Riigiraamatukogu (State Library), Reval.
FINLAND: Delegation of the Scientific Societies of Finland, Helsingfors.
FRANCE: Service Français des Echanges Internationaux, 110 Rue de Grenelle, Paris.
GERMANY: Amerika-Institut, Universitätstrasse 8, Berlin, N. W. 7.
GREAT BRITAIN AND IRELAND: Messrs. Wheldon & Wesley, 2, 3, and 4 Arthur St., New Oxford St., London W. C. 2.
GREECE: Bibliothèque Nationale, Athens.
GREENLAND, via Denmark.
GUATEMALA: Instituto Nacional de Varones, Guatemala.
HAITI: Secrétaire d'État des Relations Extérieures, Port-au-Prince.
HONDURAS: Biblioteca Nacional, Tegucigalpa.
HUNGARY: Hungarian Libraries Board, Budapest, IV.
ICELAND, via Denmark.
INDIA: Superintendent of Stationery, Bombay.
ITALY: R. Ufficio degli Scambi Internazionali, Ministero della Pubblica Istruzione, Rome.
JAMAICA: Institute of Jamaica, Kingston.
JAPAN: Imperial Library of Japan, Tokyo.
JAVA, via Netherlands.
KOREA: Government General, Seoul.
LATVIA: Service des Échanges Internationaux, Bibliothèque d'Etat de Lettonie, Riga.
LIBERIA: Bureau of Exchanges, Department of State, Monrovia.
LITHUANIA: Sent by mail.
LOURENÇO MARQUEZ, via Portugal.
LUXEMBURG, via Belgium.
MADAGASCAR, via France.
MADEIRA, via Portugal.
MOZAMBIQUE, via Portugal.

NETHERLANDS: International Exchange Bureau of the Netherlands, Royal Library, The Hague.
NEW SOUTH WALES: Public Library of New South Wales, Sydney.
NEW ZEALAND: Dominion Museum, Wellington.
NICARAGUA: Ministerio de Relaciones Exteriores, Managua.
NORWAY: Universitets-Bibliotek, Oslo.
PALESTINE: Hebrew University Library, Jerusalem.
PANAMA: Sent by mail.
PARAGUAY: Sección Canje Internacional de Publicaciones del Ministerio de Relaciones Exteriores, Estrella 563, Asuncion.
PERU: Oficina de Reparto, Depósito y Canje Internacional de Publicaciones, Ministerio de Fomento, Lima.
POLAND: Service Polonais des Echanges Internationaux, Bibliothèque du Ministère des Affaires Etrangères, Warsaw.
PORTUGAL: Secção de Trocas Internacionaes, Biblioteca Nacional, Lisbon.
QUEENSLAND: Bureau of Exchanges of International Publications, Chief Secretary's Department, Brisbane.
RUMANIA: Bureau des Echanges Internationaux, Institut Météorologique Central, Bucharest.
RUSSIA: Academy of Sciences, Leningrad.
SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.
SIAM: Department of Foreign Affairs, Bangkok.
SOUTH AUSTRALIA: Public Library of South Australia, Adelaide.
SPAIN: Servicio del Cambio Internacional de Publicaciones, Cuerpo Facultativo de Archiveros, Bibliotecarios y Arqueólogos, Madrid.
SUMATRA, via Netherlands.
SWEDEN: Kongliga Svenska Vetenskaps Akademien, Stockholm.
SWITZERLAND: Service Suisse des Échanges Internationaux, Bibliothèque Centrale Fédérale, Berne.
SYRIA: American University of Beirut.
TASMANIA: Secretary to the Premier, Hobart.
TRINIDAD: Royal Victoria Institute of Trinidad and Tobago, Port-of-Spain.
TUNIS, via France.
TURKEY: Robert College, Constantinople.
UNION OF SOUTH AFRICA: Government Printing Works, Pretoria, Transvaal.
URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.
VENEZUELA: Biblioteca Nacional, Caracas.
VICTORIA: Public Library of Victoria, Melbourne.
WESTERN AUSTRALIA: Public Library of Western Australia, Perth.
YUGOSLAVIA: Ministère des Affaires Étrangères, Belgrade.

Dr. Charles G. Abbot, who on his appointment December 16, 1918, as Assistant Secretary of the Institution, was, among other duties, assigned to the general charge of the international exchanges, has retained supervision over the exchanges since his election as Secretary of the Smithsonian Institution on January 10, 1928.

Respectfully submitted.

C. W. SHOEMAKER,
Chief Clerk, International Exchange Service.

Dr. CHARLES G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 6

REPORT ON THE NATIONAL ZOOLOGICAL PARK

SIR: I have the honor to submit the following report on the operations of the National Zoological Park for the fiscal year ending June 30, 1928. The appropriation made by Congress for the regular maintenance of the park was $175,000, and there was the usual allotment of $300 for printing and binding. Of the appropriation, $126,000 was expended for salaries and labor in connection with the maintenance of the park; $22,800 for food for animals; and $4,701 for coal.

There has been no important increase in the collection of animals, though a number of species new to the collection have been added.

ACCESSIONS

Gifts.—There were added to the collection by gift or deposit 138 specimens from 87 different donors. Notable among the gifts are a shoe-bill stork and two red birds of paradise which were purchased from the Chrysler fund. Mrs. James Cox Brady, of New York City, presented a flock of six of the beautiful Forsten's parrakeets. Col. H. A. Shumaker, of McElhattan, Pa., presented three plains wolves, a pair of which have since bred in the park.

From the United States Biological Survey, through its chief, Mr. Paul G. Redington, the park obtained a beautiful specimen of the young Kadiak bear. The acquisition of young animals is of great importance, for although the national collection is one of the most notable, many of the animals are now very old. The Yakatat bear, for instance, has been here 28 years, and young specimens, especially of the Alaskan species, are highly desirable.

Through Dr. H. C. Kellers, United States Navy, now on duty with the Marine Corps in Nicaragua, the park has received two original collections of Central American birds and animals, among them toucans, a cage of spider monkeys, and a cage of coatimundis, all of which make attractive exhibits.

DONORS

Mrs. Ethel E. Allicoate, Washington, D. C., screech owl.
American Nature Association, Washington, D. C., two European flamingoes.
Mrs. Anne Archbold, Washington, D. C., one kinkajou.
Miss Helen Louise Baldwin, Chevy Chase, Md., horned toad.

Mr. Thomas Barbour, Cambridge, Mass., musk turtle, box turtle, two spotted turtles.

Mrs. A. A. Beck, Washington, D. C., grass parrakeet.

Mr. H. S. Bickel, Brunswick, Md., two alligators.

Mr. John S. C. Boswell, Alexandria, Va., four-lined snake.

Mr. Roy M. Bott, Washington, D. C., black snake.

Miss Betty Bowman, Germantown, Md., kinkajou.

Mrs. James Cox Brady, New York City, six Forsten's parrakeets.

Mrs. Robert Callow, Washington, D. C., Cuban parrot.

Mr. F. G. Carnochan, New York City, wood tortoise, mynah bird.

Mr. M. O. Castleman, Castlemans Ferry, Va., woodchuck.

Mrs. Fred K. Chapin, Washington, D. C., two finches.

Mr. W. P. Chrysler, Detroit, Mich., shoe-bill stork, two birds of paradise.

Mr. F. M. Clark, Washington, D. C., red fox.

Mrs. E. Cocksell, Washington, D. C., double-yellow-head parrot.

President Coolidge, White House, bald eagle.

Dr. T. B. Cracroft, Washington, D. C., horned toad.

Mr. C. W. Cramer, Morgantown, W. Va., three banded rattlesnakes.

Mr. C. E. Cummings, Buffalo, N. Y., six hellbenders.

Mr. H. A. Daniel, Orange, Va., red-tailed hawk.

Señor don Pedro Domian, Limon, Costa Rica, two Costa Rica deer.

Lieut. Commander G. W. Dugger, United States Navy, alligator.

Major Erwin, Washington, D. C., gray fox.

Mrs. N. Floyd, jr., Garden City, N. Y., douroucouli.

Mr. C. W. Gaines, horned toad.

Mr. R. D. Harrison, Alexandria, Va., alligator.

Mr. Stephen Haweis, Washington, D. C., two monk parrakeets.

Mr. C. A. Henderson, Washington, D. C., great horned owl.

Mr. Albert Hochbaum, Takoma Park, D. C., barrel owl.

Horne's Zoological Arena Co., Kansas City, Mo., vervet monkey.

Mr. James Hyslop, Silver Spring, Md., copperhead.

Miss Elsie Jardine, Washington, D. C., bull snake.

Mr. L. W. Keesling, Bristol, Va., two skunks.

Dr. H. C. Kellers, United States Navy, Fifth Brigade, Managua, Nicaragua, three gray spider monkeys, two gray coatimundis, agouti, lemon-breasted toucan, two tovi parrakeets, white-throated capuchin.

Mr. John H. Kennard, Newton Center, Mass., Gila monster.

Mr. J. R. King, Takoma Park, Md., rhesus monkey.

Mrs. D. W. Knowlton, Washington, D. C., white Pekin duck.

Mr. Preston Laflin, High Point, N. C., great blue heron.

Mr. J. C. Lannam, Calderwood, Tex., black snake.

Mr. S. J. La Scola, Washington, D. C., alligator.

Mr. G. C. Leach, Bureau of Fisheries, Washington, D. C., opossum.

Mr. Harrison Lee, Bastian, Va., banded rattlesnake.

Mr. R. S. Lindamood, Salem, Va., two American black bears.

Mrs. William M. Mann, Washington, D. C., two nanday parrakeets.

Miss Mary Marsh, Chevy Chase, Md., red fox.

Mr. M. E. Musgrave, Phoenix, Ariz., puma, Bailey's lynx, Berlandier's tortoise.

Mrs. B. H. Myers, Washington, D. C., two white-tailed jack rabbits.

National Park Service, Grand Canyon, Ariz., Gila monster.

Mrs. Rose V. Nolte, Washington, D. C., double-yellow-head parrot.

Mrs. W. P. Norfolk, two brown capuchins.

Mrs. R. B. Patterson, Washington, D. C., alligator.

Pearson & Hauke, Clifton, Tex., red-tailed hawk.

Hon. Gifford Pinchot, Washington, D. C., yellow and blue macaw.

Mr. Paul G. Redington, Chief U. S. Bureau of Biological Survey, Washington, D. C., Kadiak bear.

Mr. E. B. Reid, Culpeper, Va., gray fox.

Mr. E. D. Reid, National Museum, black snake.

Lieut. E. J. Richards, United States Navy, rosella parrakeet.

Mr. Siegfried Scharbau, Washington, D. C., crimson-headed parrot.

Mr. Charles Shelby, Washington, D. C., American black bear.

Mr. H. A. Shumaker, McElhattan, Pa., and New York City, three plains wolves.

Mr. M. B. Slemmer, Centerville, Md., alligator.

Miss Stella Snell, New York City, canary.

Mrs. Sockrell, Washington, D. C., red-tailed hawk.

Mr. J. H. Stieg, Washington, D. C., osprey.

Mr. Robert F. Taylor, Washington, D. C., raccoon.

Mrs. Thomas, Garrett Park, Md., copperhead.

Miss Frances Tooke, Washington, D. C., opossum.

Mr. B. R. Torrance, Silver Spring, Md., three skunks.

Mr. G. Townsend, Colonial Beach, Va., great horned owl.

Mrs. E. M. Tracy, Washington, D. C., two coyotes.

United States Biological Survey, through Stanley G. Jewett, Portland, Oreg., albino coyote.

United States Coast Guard, New London, Conn., black bear.

United States Marine Corps, through Dr. H. C. Kellers, United States Navy, three gray spider monkeys, two gray coatimundis, agouti, lemon-breasted toucan, two tovi parrakeets, white-throated capuchin.

United States National Museum, Washington, D. C., coach-whip snake.

Miss Mabel Van Alstyne, New Rochelle, N. Y., red-fronted parrakeet.

Mr. G. H. Vega, Fort Humphreys, Va., gray fox.

Mr. A. E. Vinsen, Port au Prince, Haiti, Haitian snake.

Mr. C. T. Vorhies, Tucson, Ariz., three Gila monsters.

Mr. Edward White, Washington, D. C., two alligators.

Mr. W. L. Whiting, Takoma Park, Md., raccoon.

Mr. J. S. Williams, Widewater, Va., green guenon.

Mr. W. C. Williams, Franklin, Tenn., banded rattlesnake.

Unknown donors, great blue heron, turkey vultures, broad-winged hawk, two alligators.

The office of the Chief Coordinator has again transferred certain useful and appreciated equipment and supplies to the park.

Births.—Among the births of the park this year have been yak, tahr, American elk, Alpine ibex, mouflon, barasingha deer, hog deer, fallow deer, red deer, Sika deer, bison, mountain sheep, llama, gray wolves, aoudads, wart hogs, agouti, rhesus monkey, and leopards. Both pairs of leopards secured by the Smithsonian-Chrysler expedition mated in the zoo and each produced a litter of two cubs, which are doing well. An American white pelican was raised in the pelican pond near the Harvard Street entrance, which is the first breeding record of this bird in captivity, and two more blue geese have been hatched. The herd of Rocky Mountain sheep was augmented by

2 lambs, and at the close of the year there were 10 individuals—8 born in the park and 4 of them grandchildren.

Exchanges.—The most important of the animals received in exchange were a mate to the Mongolian wild horse which we already had, a pair of South African big-eared foxes, and a collection of eight species of lories.

Purchases.—The principal purchases of the year were a young South African buffalo; an inyala, the first of its kind to reach America; a pair of brown hyena, also unique of their kind in America; three wolverines secured by Dr. W. H. Chase, of Cordova, Alaska; a rhinoceros horn-bill; and a hyacinthine macaw.

La Société Nationale d'Acclimatation de France during the year awarded the park its medal in recognition of the raising of the blue goose.

Removals.—Losses by death include the two giraffes, Hi-boy and Dot, both of which died of nephritis with complications. Other serious losses are a Kadiak bear, which had lived in the park from December 15, 1903, to August 28, 1927; white-tailed gnu, arrived June 23, 1914, died November 21, 1927; a sambar deer, received May 22, 1912, died January 2, 1928; our last cheetah, which had arrived August 8, 1913, died September 6, 1927; an American bison, born in the zoo May 24, 1907, died September 4, 1927; jaguar, arrived May 1, 1915, died June 28, 1928; European black stork, arrived May 18, 1902, died May 13, 1928; West African crowned crane, arrived May 25, 1905, died February 21, 1928; gila monster, received September 21, 1910, died January 11, 1928; anaconda, received August 17, 1899, died August 26, 1927.

The long life of the cheetah is a record for an individual of its species living in the North, and the anaconda, having lived for 28 years in the park, provides a most notable record for longevity of this snake, which is usually not hardy in captivity.

The loss in the reptile collection has been great, as we have no suitable quarters for them.

Post-mortem examinations were made in most cases by the pathological division of the Bureau of Animal Industry. The following list shows the results of autopsies:

CAUSES OF DEATH

MAMMALS

Carnivora: Acute peritonitis, 1; intestinal obstruction, 1; gastritis, 2.

Primates: Chronic nephritis, 1; pneumonia, 5; gastroenteritis, 3; cachexia senilis, 1.

Artiodactyla: Nephritis, 2; gastroenteritis, 1; septic metritis, 1; pneumonia, 3; old age, 1.

Rodentia: Pneumonia, 1.

BIRDS

Sphenisciformes: Peritonitis, 1.
Ciconiiformes: Ruptured liver, 1; edema of heart, 1.
Charadriiformes: Pneumonia, 1.
Coraciiformes: Aspergillosis, 1.
Psittaciformes: Acute enteritis, 1.

The animals lost by death which were valuable for museum purposes were transferred to the United States National Museum for preservation. A number of rare birds' eggs were also sent to the Museum.

A few mammals especially desired by the department of anatomy of the Johns Hopkins Medical School were sent, after death, to that institution.

ANIMALS IN THE COLLECTION JUNE 30, 1928

MAMMALS

MARSUPIALIA

Virginia opossum (*Didelphis virginiana*)	4
Flying phalanger (*Petaurus breviceps*)	5
Bush-tailed rock wallaby (*Petrogale penicillata*)	1
Wallaroo (*Macropus robustus*)	2
Wombat (*Phascolomys mitchelli*)	1

CARNIVORA

Kadiak bear (*Ursus middendorffi*)	2
Alaska Peninsula bear (*Ursus gyas*)	4
Yakutat bear (*Ursus dalli*)	1
Kidder's bear (*Ursus kidderi*)	2
European bear (*Ursus arctos*)	7
Grizzly bear (*Ursus horribilis*)	1
Apache grizzly (*Ursus apache*)	1
Himalayan bear (*Ursus thibetanus*)	1
Black bear (*Euarctos americanus*)	7
Cinnamon bear (*Euarctos americanus cinnamomum*)	4
Glacier bear (*Euarctos emmonsii*)	1
Sun bear (*Helarctos malayanus*)	1
Polar bear (*Thalarctos maritimus*)	2
Dingo (*Canis dingo*)	2
Gray wolf (*Canis nubilus*)	13
Florida wolf (*Canis floridanus*)	1
Texas red wolf (*Canis rufus*)	1
Coyote (*Canis latrans*)	5
Hybrid coyote (*Canis latrans-rufus*)	4
California coyote (*Canis ochropus*)	1
Black-backed jackal (*Thos mesomelas*)	1
Fennec (*Fennecus zerda*)	2
Rough fox (*Cerdocyon cancrivorus*)	2
Red fox (*Vulpes fulva*)	7
Silver-black fox (*Vulpes fulva*)	1
European fox (*Vulpes vulpes*)	1
Kit fox (*Vulpes velox*)	2
Gray fox (*Urocyon cinereoargenteus*)	5
Bush dog (*Icticyon venaticus*)	1
Cacomistle (*Bassariscus astutus*)	1
Raccoon (*Procyon lotor*)	16
Florida raccoon (*Procyon lotor elucus*)	1
Gray coatimundi (*Nasua narica*)	4
Kinkajou (*Potos flavus*)	2
Mexican kinkajou (*Potos flavus aztecus*)	1
Fisher (*Martes pennanti*)	1
Skunk (*Mephitis nigra*)	7
Wolverine (*Gulo luscus*)	3
American badger (*Taxidea taxus*)	2
Ratel (*Mellivora capensis*)	1
Florida otter (*Lutra canadensis vaga*)	2
Indian civet (*Viverra zibetha*)	1
Palm civet (*Paradoxurus hermaphroditus*)	1
Egyptian mongoose (*Herpestes ichneumon*)	1
Neumann's genet (*Genetta dongalana neumanni*)	5
Aard-wolf (*Proteles cristatus*)	1
Spotted hyena (*Crocuta crocuta*)	1
East African spotted hyena (*Crocuta crocuta germinans*)	5
Striped hyena (*Hyæna hyæna*)	1
Brown hyena (*Hyæna brunnea*)	2
Lion (*Felis leo*)	5
Bengal tiger (*Felis tigris*)	1
Manchurian tiger (*Felis tigris longipilis*)	3
Leopard (*Felis pardus*)	1
Black leopard (*Felis pardus*)	1
East African leopard (*Felis pardus suahelicus*)	8
Serval (*Felis serval*)	1
East African serval (*Felis capensis hindei*)	2
Ocelot (*Felis pardalis*)	2
Brazilian ocelot (*Felis pardalis brasiliensis*)	1
Gray tiger-cat (*Felis chrysothrix*)	1
Mexican puma (*Felis azteca*)	4

Mountain lion (*Felis hippolestes*)	1
Yaguarundi (*Felis yagouaroundi*)	1
Indian caracal (*Lynx caracal*)	1
Abyssinian caracal (*Lynx caracal nubica*)	1
Canada lynx (*Lynx canadensis*)	1
Bay lynx (*Lynx rufus*)	3
Bailey's lynx (*Lynx baileyi*)	1
Clouded leopard (*Neofelis nebulosa*)	1

PINNIPEDIA

California sea-lion (*Zalophus californianus*)	1
Leopard seal (*Phoca richardii var.*)	2
San Geronimo harbor seal (*Phoca richardii geronimensis*)	1

RODENTIA

Woodchuck (*Marmota monax*)	7
Prairie dog (*Cynomys ludovicianus*)	11
Albino squirrel (*Sciurus carolinensis*)	2
American beaver (*Castor canadensis*)	2
East African porcupine (*Hystrix galeata*)	2
Malay porcupine (*Acanthion brachyurum*)	2
Viscacha (*Lagostomus trichodactylus*)	1
Central American paca (*Cuniculus paca virgatus*)	4
Trinidad agouti (*Dasyprocta rubrata*)	4
Guinea pig (*Cavia porcellus*)	10

LAGOMORPHA

Domestic rabbit (*Oryctolagus cuniculus*)	10

INSECTIVORA

European hedgehog (*Erinaceus europœus*)	1

PRIMATES

Zanzibar lemur (*Galago garnetti*)	1
Red-fronted lemur (*Lemur rufifrons*)	1
Black lemur (*Lemur macaco*)	1
Douroucouli (*Aotus trivirgatus*)	1
Gray spider monkey (*Ateles geoffroyi*)	7
White-throated capuchin (*Cebus capucinus*)	2
Brown capuchin (*Cebus fatuellus*)	1
Margarita capuchin (*Cebus margaritæ*)	1
Chacma (*Papio porcarius*)	2
Anubis baboon (*Papio cynocephalus*)	6
Olive baboon (*Papio neumanni*)	3
Hamadryas baboon (*Papio hamadryas*)	1
Mandrill (*Papio sphinx*)	3
Drill (*Papio leucophœus*)	1
Moor monkey (*Cynopithecus maurus*)	3
Black ape (*Cynopithecus niger*)	1
Barbary ape (*Simia sylvanus*)	2
Japanese macaque (*Macaca fuscata*)	3
Brown macaque (*Macaca arctoides*)	1
Pig-tailed monkey (*Macaca nemestrina*)	1
Burmese macaque (*Macaca andamanensis*)	1
Rhesus monkey (*Macaca rhesus*)	7
Crab-eating macaque (*Macaca irus*)	1
Philippine macaque (*Macaca syrichta*)	2
Javan macaque (*Macaca mordax*)	3
Sooty mangabey (*Cercocebus fuliginosus*)	3
Green guenon (*Lasiopyga callitrichus*)	2
Vervet (*Lasiopyga pygerythra*)	1
Johnston's vervet (*Lasiopyga pygerythra johnstoni*)	5
Mozambique monkey (*Lasiopyga* sp.)	2
Sykes' guenon (*Lasiopyga albigularis*)	5
Mona guenon (*Lasiopyga mona*)	2
De Brazza's guenon (*Lasiopyga brazzæ*)	1
Lesser white-nosed guenon (*Lasiopyga petaurista*)	1
Patas guenon (*Erythrocebus patas*)	1
White-handed gibbon (*Hylobates lar*)	1
Gray gibbon (*Hylobates leuciscus*)	1
Chimpanzee (*Pan satyrus*)	2
Orang-utan (*Pongo pygmæus*)	1

ARTIODACTYLA

Wart hog (*Phacochœrus æthiopicus*)	3
River hog (*Potamochœrus africanus*)	4
Collared peccary (*Pecari angulatus*)	2
Hippopotamus (*Hippopotamus amphibius*)	2
Pigmy hippopotamus (*Chœropsis liberiensis*)	1
Bactrian camel (*Camelus bactrianus*)	1
Arabian camel (*Camelus dromedarius*)	1
Guanaco (*Lama huanachus*)	2
Llama (*Lama glama*)	6
Reindeer (*Rangifer tarandus*)	9
Fallow deer (*Dama dama*)	10
White fallow deer (*Dama dama*)	1
Axis deer (*Axis axis*)	2
Hog deer (*Hyelaphus porcinus*)	5
Barasingha (*Rucervus duvaucelii*)	6
Burmese deer (*Rucervus eldii*)	1
Japanese deer (*Sika nippon*)	12
Red deer (*Cervus elaphus*)	15
Kashmir deer (*Cervus hanglu*)	2
Bedford deer (*Cervus xanthopygus*)	5
American elk (*Cervus canadensis*)	5
Costa Rican deer (*Odocoileus sp.*)	2
Guatemala deer (*Odocoileus sp.*)	1
Mule deer (*Odocoileus hemionus*)	3
Blesbok (*Damaliscus albifrons*)	1
White-tailed gnu (*Connochœtes gnu*)	1
Brindled gnu (*Connochœtes taurinus*)	1
White-bearded gnu (*Connochœtes taurinus albojubatus*)	2
Lechwe (*Onotragus leche*)	1
Inyala (*Tragelaphus angasi*)	1
Sable antelope (*Egocerus niger*)	1

Reed buck (*Redunca bohor*)	1
East African impalla (*Æpyceros melampus suara*)	2
Indian antelope (*Antilope cervicapra*)	2
Nilgai (*Boselaphus tragocamelus*)	2
Mountain goat (*Oreamnos americanus*)	3
Tahr (*Hemitragus jemlahicus*)	10
Alpine ibex (*Capra ibex*)	2
Aoudad (*Ammotragus lervia*)	3
Rocky Mountain sheep (*Ovis canadensis*)	11
Mouflon (*Ovis europœus*)	7
Greenland musk-ox (*Ovibos moschatus wardi*)	1
Zebu (*Bos indicus*)	1
Yak (*Poëphagus grunniens*)	6
American bison (*Bison bison*)	14
Anoa (*Anoa depressicornis*)	1
Indian buffalo (*Bubalus bubalis*)	2

PERISSODACTYLA

Malay tapir (*Tapirus indicus*)	1
Brazilian tapir (*Tapirus terrestris*)	1
Baird's tapir (*Tapirella bairdii*)	1
Mongolian horse (*Equus przewalskii*)	2
Mountain zebra (*Equus zebra*)	2
Chapman's zebra (*Equus quagga chapmani*)	2
Zebra-horse hybrid (*Equus grevyi-caballus*)	1
Zebra-ass hybrid (*Equus grevyi-asinus*)	1

PROBOSCIDEA

Abyssinian elephant (*Loxodonta africana oxyotis*)	1
Sumatran elephant (*Elephas sumatranus*)	1

BIRDS

STRUTHIONIFORMES

South African ostrich (*Struthio australis*)	3
Somaliland ostrich (*Struthio molybdophanes*)	1
Nubian ostrich (*Struthio camelus*)	1

RHEIFORMES

Rhea (*Rhea americana*)	1

CASUARIIFORMES

Australian cassowary (*Casuarius australis*)	1
Single-wattled cassowary (*Casuarius uniappendiculatus*)	1
Sclater's cassowary (*Casuarius philipi*)	1
Emu (*Dromiceius novæhollandiæ*)	2

CICONIIFORMES

American white pelican (*Pelecanus erythrorhynchos*)	9
European white pelican (*Pelecanus onocrotalus*)	2
Roseate pelican (*Pelecanus roseus*)	1
Australian pelican (*Pelecanus conspicillatus*)	2
Brown pelican (*Pelecanus occidentalis*)	6
California brown pelican (*Pelecanus californicus*)	5
Florida cormorant (*Phalacrocorax auritus floridanus*)	2
Brandt's cormorant (*Phalacrocorax penicillatus*)	1
Great white heron (*Ardea occidentalis*)	1
Great blue heron (*Ardea herodias*)	3
Hybrid great blue and white heron (*Ardea herodias-occidentalis*)	1
Goliath heron (*Ardea goliath*)	1
East African heron (*Ardea melanocephala*)	1
Black-crowned night heron (*Nycticorax nycticorax nævius*)	79
Boat-bill (*Cochlearius cochlearius*)	1
White-necked stork (*Dissura episcopus*)	2
Indian adjutant (*Leptoptilus dubius*)	2
Shoe-bill (*Balæniceps rex*)	1
Wood ibis (*Mycteria americana*)	1
Sacred ibis (*Threskiornis æthiopicus*)	1
Black-headed ibis (*Threskiornis melanocephalus*)	3
White ibis (*Guara alba*)	8
Scarlet ibis (*Guara rubra*)	3
European flamingo (*Phœnicopterus roseus*)	1

ANSERIFORMES

Mallard (*Anas platyrhynchos*)	26
Black duck (*Anas rubripes*)	7
Australian black duck (*Anas superciliosa*)	1
Gadwall (*Chaulelasmus streperus*)	12
Falcated teal (*Eunetta falcata*)	1
European widgeon (*Mareca penelope*)	3
Baldpate (*Mareca americana*)	7
Green-winged teal (*Nettion carolinense*)	3
European teal (*Nettion crecca*)	4
Baikal teal (*Nettion formosum*)	5
Blue-winged teal (*Querquedula discors*)	1
Garganey (*Querquedula querquedula*)	6
Shoveller (*Spatula clypeata*)	1
African pintail (*Dafila erythrorhyncha*)	2
Pintail (*Dafila acuta*)	11
Wood duck (*Aix sponsa*)	8
Mandarin duck (*Dendronessa galericulata*)	8
Canvasback (*Marila valisineria*)	7
European pochard (*Marila ferina*)	3
Redhead (*Marila americana*)	11
Ring-necked duck (*Marila collaris*)	2
Tufted duck (*Marila fuligula*)	1
Lesser scaup duck (*Marila affinis*)	1
Greater scaup duck (*Marila marila*)	3

Rosy-billed pochard (*Metopiana peposaca*)	4
Egyptian goose (*Chenalopex ægyptiacus*)	1
Hawaiian goose (*Nesochen sandvicensis*)	2
Blue goose (*Chen cærulescens*)	7
White-fronted goose (*Anser albifrons*)	4
American white-fronted goose (*Anser albifrons gambeli*)	1
Bean goose (*Anser fabalis*)	2
Pink-footed goose (*Anser brachyrhynchus*)	2
Chinese goose (*Cygnopsis cygnoides*)	3
Bar-headed goose (*Eulabeia indica*)	2
Canada goose (*Branta canadensis*)	9
Hutchins's goose (*Branta canadensis hutchinsii*)	3
White-cheeked goose (*Branta canadensis occidentalis*)	15
Cackling goose (*Branta canadensis minima*)	2
Brant (*Branta bernicla glaucogastra*)	10
Barnacle goose (*Branta leucopsis*)	4
Emperor goose (*Philacte canagica*)	1
Spur-winged goose (*Plectropterus gambensis*)	4
Muscovy duck (*Cairina moschata*)	3
Black-bellied tree duck (*Dendrocygna autumnalis*)	1
Eyton's tree duck (*Dendrocygna eytoni*)	5
Mute swan (*Cygnus gibbus*)	1
Whistling swan (*Cygnus columbianus*)	1
Black swan (*Chenopis atrata*)	4

FALCONIFORMES

Condor (*Vultur gryphus*)	1
California condor (*Gymnogyps californianus*)	3
Turkey vulture (*Cathartes aura*)	6
Black vulture (*Coragyps urubu*)	1
King vulture (*Sarcoramphus papa*)	2
Secretary bird (*Sagittarius serpentarius*)	1
Griffon vulture (*Gyps fulvus*)	1
African black vulture (*Torgos tracheliotus*)	1
Cinereous vulture (*Ægypius monachus*)	2
White-headed vulture (*Trigonoceps occipitalis*)	1
Caracara (*Polyborus cheriway*)	3
Wedge-tailed eagle (*Uroaëtus audax*)	2
Golden eagle (*Aquila chrysaëtos*)	4
Tawny eagle (*Aquila rapax*)	2
Bald eagle (*Haliæetus leucocephalus leucocephalus*)	10
Alaskan bald eagle (*Haliæetus leucocephalus alascanus*)	2
Red-tailed hawk (*Buteo borealis*)	12
Broad-winged hawk (*Buteo platypterus*)	1
East African chanting goshawk (*Melierax poliopterus*)	1
Pigmy falcon (*Poliohierax semitorquatus*)	1
Sparrow hawk (*Falco sparverius*)	3
Osprey (*Pandion haliaëtus carolinensis*)	2

GALLIFORMES

Panama curassow (*Crax panamensis*)	2
Spix's wattled curassow (*Crax globulosa*)	3
Razor-billed curassow (*Mitu mitu*)	2
Crested guan (*Penelope boliviana*)	1
Chestnut-winged guan (*Ortalis garrula*)	1
Vulturine guinea fowl (*Acryllium vulturinum*)	2
Grant's crested guinea fowl (*Guttera granti*)	1
Reichenow's helmeted guinea fowl (*Numida mitrata reichenowi*)	12
Peafowl (*Pavo cristatus*)	10
Albino peafowl (*Pavo cristatus*)	4
Javan jungle fowl (*Gallus varius*)	2
Argus pheasant (*Argus giganteus*)	2
Silver pheasant (*Gennæus nycthemerus*)	2
Edward's pheasant (*Gennæus edwardsi*)	1
Golden pheasant (*Chrysolophus pictus*)	5
Lady Amherst's pheasant (*Chrysolophus amherstiæ*)	1
Ring-necked pheasant (*Phasianus torquatus*)	11
Migratory quail (*Coturnix coturnix*)	10
Valley quail (*Lophortyx californica vallicola*)	1
Scaled quail (*Callipepla squamata*)	4
Crowned wood partridge (*Rollulus cristatus*)	2

GRUIFORMES

Florida gallinule (*Gallinula chloropus galeata*)	1
East Indian gallinule (*Porphyrio calvus*)	1
Pukeko (*Porphyrio stanleyi*)	1
Black-tailed moor hen (*Microtribonyx ventralis*)	2
American coot (*Fulica americana*)	1
African moor hen (*Fulica cristata*)	4
African black crake (*Limnocrax flavirostra*)	1
Lesser rail (*Hypotænidia philippensis*)	2
South Island weka rail (*Ocydromus australis*)	2
Short-winged weka (*Ocydromus brachypterus*)	2
Sandhill crane (*Megalornis mexicana*)	4
Little brown crane (*Megalornis canadensis*)	3
White-necked crane (*Megalornis leucauchen*)	1

Indian white crane (*Megalornis leucogeranus*)	1
Lilford's crane (*Megalornis lilfordi*)	1
Australian crane (*Mathewsena rubicunda*)	2
Demoiselle crane (*Anthropoides virgo*)	3
East African crowned crane (*Balearica regulorum gibbericeps*)	5
Kagu (*Rhynochetos jubatus*)	2

CHARADRIIFORMES

Ruff (*Philomachus pugnax*)	3
South American stone plover (*Œdicnemus bistriatus vocifer*)	1
Pacific gull (*Gabianus pacificus*)	1
Great black-backed gull (*Larus marinus*)	2
Western gull (*Larus occidentalis*)	6
Herring gull (*Larus argentatus*)	3
Silver gull (*Larus novæhollandiæ*)	30
Laughing gull (*Larus atricilla*)	2
Inca tern (*Noddi inca*)	1
Victoria crowned pigeon (*Goura victoria*)	1
Nicobar pigeon (*Calœnas nicobarica*)	2
Bronze-wing pigeon (*Phaps chalcoptera*)	2
Bleeding-heart dove (*Gallicolumba luzonica*)	9
Wood pigeon (*Columba palumbus*)	7
Triangular spotted pigeon (*Columba guinea*)	3
Fiji Island pigeon (*Janthoenas vitiensis*)	1
Mourning dove (*zenaidura macroura carolinensis*)	1
Mexican dove (*Zenaidura graysoni*)	1
White-fronted dove (*Leptotila fulviventris brachyptera*)	4
Necklace dove (*Spilopelia tigrina*)	3
Emerald-spotted dove (*Turtur chalcospilos*)	22
Ringed turtledove (*Streptopelia risoria*)	5
East African ring-necked dove (*Streptopelia capicola tropica*)	31
Masai mourning dove (*Streptopelia decipiens perspicillata*)	12
Zebra dove (*Geopelia striata*)	3
Bar-shouldered dove (*Geopelia humeralis*)	1
Cape masked dove (*Œna capensis*)	12
Inca dove (*Scardafella inca*)	1
Cuban ground dove (*Chæmepelia passerina aflavida*)	1
Pacific fruit pigeon (*Globicera pacifica*)	1
Bronze fruit pigeon (*Muscadivores ænea*)	1

PSITTACIFORMES

Kea (*Nestor notabilis*)	1
Violet-necked lory (*Eos variegata*)	2
Forsten's lorikeet (*Trichoglossus forsteni*)	4
Great black cockatoo (*Microglossus aterrimus*)	1
Roseate cockatoo (*Kakatoe roseicapilla*)	13
Bare-eyed cockatoo (*Kakatoe gymnopis*)	1
Leadbeater's cockatoo (*Kakatoe leadnopis*)	1
White cockatoo (*Kakatoe alba*)	1
Sulphur-crested cockatoo (*Kakatoe galerita*)	6
Great red-crested cockatoo (*Kakatoe moluccensis*)	1
Mexican green macaw (*Ara militaris mexicana*)	2
Severe macaw (*Ara severa*)	1
Blue and yellow macaw (*Ara ararauna*)	9
Red and blue and yellow macaw (*Ara macao*)	4
Illiger's macaw (*Ara maracana*)	2
Hyacinthine macaw (*Anodorhynchus hyacinthinus*)	1
Blue-winged conure (*Pyrrhura picta*)	2
Nanday paroquet (*Nandayus nenday*)	3
Gray-breasted paroquet (*Myopsitta monachus*)	3
Petz's paroquet (*Eupsittula canicularis*)	5
Golden-crowned paroquet (*Eupsittula aurea*)	2
Weddell's paroquet (*Eupsittula weddellii*)	3
Blue-winged parrotlet (*Psittacula passerina*)	12
Golden paroquet (*Brotogeris chrysosema*)	1
Tovi paroquet (*Brotogeris jugularis*)	4
Yellow-naped parrot (*Amazona auropalliata*)	2
Mealy parrot (*Amazona farinosa*)	1
Orange-winged parrot (*Amazona amazonica*)	5
Blue-fronted parrot (*Amazona æstiva*)	1
Red-crowned parrot (*Amazona viridigenalis*)	4
Double-yellow-head parrot (*Amazona oratrix*)	13
Yellow-headed parrot (*Amazona ochrocephala*)	7
Festive parrot (*Amazona festiva*)	3
Lesser white-fronted parrot (*Amazona albifrons nana*)	1
Santo Domingo parrot (*Amazona ventralis*)	3
Cuban parrot (*Amazona leucocephala*)	6
Maximilian's parrot (*Pionus maximiliani*)	1
Dusky parrot (*Pionus fuscus*)	1
Blue-headed parrot (*Pionus menstruus*)	1
Amazonian caique (*Pionites xanthomera*)	3
Hawk-head parrot (*Deroptyus accipitrinus*)	1

Yellow-fronted parrot (*Poicephalus flavifrons*)	1
East African brown parrot (*Poicephalus meyeri matschiei*)	2
Congo parrot (*Poicephalus gulielmi*)	1
Lesser vasa parrot (*Coracopsis nigra*)	1
Greater vasa parrot (*Coracopsis vasa*)	1
Red-faced love bird (*Agapornis pullaria*)	7
Gray-headed love bird (*Agapornis madagascariensis*)	8
Yellow-collared love bird (*Agapornis personata*)	5
Fischer's love bird (*Agapornis fischeri*)	4
Nyassa love bird (*Agapornis lilianæ*)	11
Blue-crowned hanging paroquet (*Loriculus galgulus*)	1
Blue-bonnet paroquet (*Psephotus hæmatorrhous*)	1
Pennant's paroquet (*Platycercus elegans*)	1
Rosella paroquet (*Platycercus eximius*)	1
Crimson-winged paroquet (*Aprosmictus erythropterus*)	1
Ring-necked paroquet (*Conurus torquatus*)	1
Nepalese paroquet (*Conurus nepalensis*)	2
Long-tailed paroquet (*Conurus longicauda*)	1
Blossom-head paroquet (*Conurus cyanocephala*)	1
Grass paroquet (*Melopsittacus undulatus*)	12

CORACIIFORMES

Rhinoceros hornbill (*Buceros rhinoceros*)	1
Jackson's hornbill (*Lophoceros jacksoni*)	1
Sulphur-breasted toucan (*Ramphastos carinatus*)	2
Emin Pasha's barbet (*Trachyphonus emini*)	1
Barred owl (*Strix varia varia*)	11
Florida barred owl (*Strix varia alleni*)	1
Snowy owl (*Nyctea nyctea*)	1
Screech owl (*Otus asio*)	4
Great horned owl (*Bubo virginianus*)	15
Eagle owl (*Bubo bubo*)	1
American barn owl (*Tyto alba pratincola*)	7
African barn owl (*Tyto alba affinis*)	2
Red-shafted flicker (*Colaptes cafer collaris*)	1

PASSERIFORMES

Cock of the rock (*Rupicola rupicola*)	1
Naked-throated bell-bird (*Chasmorhynchus nudicollis*)	1
Red-billed hill-tit (*Liothrix luteus*)	19
Black-gorgeted laughing thrush (*Garrulax pectoralis*)	2
White-eared bulbul (*Otocompsa leucotis*)	3
Red-eared bulbul (*Otocompsa jocosa*)	3
Black-headed bulbul (*Molpastes hæmorrhous*)	3
Piping crow-shrike (*Gymnorhina tibicen*)	1
White-necked raven (*Corvultur albicollis*)	1
European raven (*Corvus corax*)	1
American raven (*Corvus corax sinuatus*)	5
Australian crow (*Corvus coronoides*)	1
American crow (*Corvus brachyrhynchos*)	1
White-breasted crow (*Corvus albus*)	2
American magpie (*Pica pica hudsonia*)	1
Yucatan jay (*Cissilopha yucatanica*)	1
Blue jay (*Cyanocitta cristata*)	2
Green jay (*Xanthoura luxuosa*)	2
Pileated jay (*Cyanocorax pileatus*)	2
Blue honey-creeper (*Cyanerpes cyaneus*)	1
Blue-winged tanager (*Tanagra cyanoptera*)	1
Blue tanager (*Thraupis cana*)	1
Giant whydah (*Diatropura progne*)	1
Paradise whydah (*Steganura paradisea*)	2
Red-crowned bishop bird (*Pyromelana sylvatica*)	12
Red-billed weaver (*Quelea quelea*)	5
Buffalo weaver (*Textor albirostris*)	2
Black-winged coral-billed weaver (*Textor niger nyassae*)	25
Madagascar weaver (*Foudia madagascariensis*)	6
Black-headed weaver (*Hyphanturgus nigriceps*)	30
Emin's scaly-headed finch (*Sporopipes frontalis emini*)	25
St. Helena waxbill (*Estrilda astrilda*)	4
Orange-cheeked waxbill (*Estrilda melpoda*)	1
Rosy-rumped waxbill (*Estrilda rhodopygia*)	1
Blue-headed blue waxbill (*Uræginthus bengalus cyanocephalus*)	3
East African fire-throated finch (*Pytilia kirki*)	10
Strawberry finch (*Amandava amandava*)	24
Nutmeg finch (*Munia punctulata*)	50
White-headed nun (*Munia maja*)	1
Black-headed nun (*Munia atricapilla*)	18
Chestnut-breasted finch (*Munia castaneithorax*)	2
Java finch (*Munia oryzivora*)	27
Masked grass finch (*Poëphila personata*)	5
Diamond finch (*Steganopleura guttata*)	1
Zebra finch (*Tæniopygia castanotis*)	15
Cutthroat finch (*Amadina fasciata*)	14
Tanganyika cutthroat finch (*Amadina fasciata alexanderi*)	12

Red-headed finch (*Amadina erythrocephala*)	2
Yellow-headed marshbird (*Agelaius icterocephalus*)	1
Australian gray jumper (*Struthidea cinerea*)	1
Shining starling (*Lamprocorax metallicus*)	1
Southern glossy starling (*Lamprocolius pestis*)	4
Crested starling (*Galeopsar salvadorii*)	1
White-capped starling (*Heteropsar albicapillus*)	1
Indian mynah (*Acridotheres tristis*)	1
Crested mynah (*Æthiopsar cristatellus*)	1
Malay grackle (*Gracula javana*)	1
Bar-jawed troupial (*Gymnomystax melanicterus*)	1
Hooded oriole (*Icterus cucullatus*)	1
Yellow-tailed oriole (*Icterus mesomelas*)	1
Purple grackle (*Quiscalus quiscula*)	1
Greenfinch (*Chloris chloris*)	3
European goldfinch (*Carduelis carduelis*)	4
Brambling (*Fringilla montifringilla*)	4
Yellowhammer (*Emberiza citrinella*)	1
House finch (*Carpodacus mexicanus frontalis*)	2
San Lucas house finch (*Carpodacus mexicanus ruberrimus*)	2
Canary (*Serinus canarius*)	6
Little yellow serin (*Serinus icterus*)	15
Gray singing finch (*Serinus leucopygius*)	9
White-throated sparrow (*Zonotrichia albicollis*)	1
San Diego song sparrow (*Melospiza melodia cooperi*)	2
Coastal pale-bellied sparrow (*Passer griseus suahelicus*)	20
Saffron finch (*Sicalis flaveola*)	9
Blue grosbeak (*Guiraca cœrulea*)	2
Chinese grosbeak (*Eophona migratoria sowerbyi*)	1
Red-crested cardinal (*Paroaria cucullata*)	3

REPTILES

Alligator (*Alligator mississipiensis*)	27
Horned toad (*Phrynosoma cornutum*)	9
Gila monster (*Heloderma suspectum*)	8
Beaded lizard (*Heloderma horridum*)	1
Gould's monitor (*Varanus gouldii*)	1
Egyptian monitor (*Varanus niloticus*)	1
Philippine monitor (*Varanus salvator*)	1
West Indian iguana (*Cyclura cornuta*)	1
Ball python (*Python regius*)	1
Rock python (*Python molurus*)	1
Regal python (*Python reticulatus*)	1
African python (*Python sebæ*)	10
Anaconda (*Eunectes murinus*)	2
Boa constrictor (*Constrictor constrictor*)	3
Porto Rican tree-boa (*Epicrates angulifer*)	5
Brazilian tree-boa (*Epicrates crassus*)	1
Black snake (*Coluber constrictor*)	1
Corn snake (*Elaphe guttata*)	1
Pine snake (*Pituophis melanoleucus*)	2
King snake (*Lampropeltis getulus*)	1
Four-lined snake (*Elaphe 4-vittata*)	1
Hog-nosed snake (*Heterodon platyrhinos*)	1
Water snake (*Natrix sipedon*)	2
Egyptian cobra (*Naja haie*)	2
Black-necked spitting cobra (*Naja nigricollis*)	1
Copperhead (*Agkistrodon mokasen*)	5
Fer-de-lance (*Bothrops lanceolatus*)	1
Florida rattlesnake (*Crotalus adamanteus*)	2
Western diamond rattlesnake (*Crotalus atrox*)	1
Banded rattlesnake (*Crotalus horridus*)	4
Snapping turtle (*Chelydra serpentina*)	2
Florida snapping turtle (*Chelydra osceola*)	1
African mud terrapin (*Pelusius nigricans*)	26
African snake-necked terrapin (*Pelomedusa galeata*)	40
Brazilian snake-necked terrapin (*Hydraspis hilarii*)	1
Diamond-back terrapin (*Malaclemys centrata*)	2
Geographic terrapin (*Graptemys geographica*)	1
Musk turtle (*Sternotherus odoratus*)	1
Mexican musk turtle (*Kinosternon sonoriense*)	1
South American musk turtle (*Kinosternon scorpioides*)	5
Pennsylvania musk turtle (*Kinosternon subrubrum*)	2
Wood turtle (*Clemmys insculpta*)	3
Leprous terrapin (*Clemmys leprosa*)	1
Muhlenberg's terrapin (*Clemmys muhlenbergi*)	2
Blanding's terrapin (*Emys blandingii*)	2
European pond turtle (*Emys orbicularis*)	3
South American terrapin (*Nicoria punctularia*)	1
Reeves turtle (*Geoclemys reevesi*)	1
Loochoo turtle (*Geoemyda spengleri*)	1
Ceylon terrapin (*Geoemyda thermalis*)	6
Painted turtle (*Chrysemys picta*)	2
Western painted turtle (*Chrysemys belli*)	1
Gopher tortoise (*Gopherus polyphemus*)	1
Duncan Island tortoise (*Testudo ephippium*)	3

Indefatigable Island tortoise (*Testudo porteri*)	1
Albemarle Island tortoise (*Testudo vicina*)	2
South American tortoise (*Testudo denticulata*)	1
Angulated tortoise (*Testudo angulata*)	1
Bell's tortoise (*Testudo belli*)	3
Leopard tortoise (*Testudo pardalis*)	6
Agassiz's tortoise (*Testudo agassizii*)	1
Berlandier's tortoise (*Testudo berlandieri*)	1
Iberian tortoise (*Testudo iberia*)	1
Soft-shelled tortoise (*Testudo loveridgei*)	8
Chicken turtle (*Deirochelys reticularia*)	1

BATRACHIANS

African smooth-clawed frog (*Xenopus mulleri*)	28
Giant salamander (*Megalobatrachus japonicus*)	2

Statement of the collection

	Mammals	Birds	Reptiles and batrachians	Total
Presented	47	40	51	138
Born	49	29		78
Received in exchange	16	16	3	35
Purchased	30	76	6	112
Transferred from other Government departments	3			3
Total	145	161	60	336

SUMMARY

Animals on hand July 1, 1927	2, 366
Accessions during the year	366
Total animals handled	2, 732
Deduct loss (by death, return of animals, and exchange)	459
	2, 273

Status of collection

	Species	Individuals
Mammals	186	529
Birds	329	1, 481
Reptiles and batrachians	67	263
Total	582	2, 273

VISITORS

The estimated attendance as recorded in the daily reports of the park was somewhat smaller than last year, when the interest of the public in the Smithsonian-Chrysler expedition brought great crowds of visitors; however, it is higher than any other year in the history of the zoo, and from observation the number of out-of-town visitors was unusually great. One morning there were 1,100 visitors from the State of Pennsylvania and another morning 750 from the same State. Automobile license tags show that visitors come from every State in the Union.

Attendance by months was as follows:

1927		1928	
July	303, 800	January	65, 150
August	266, 900	February	68, 875
September	307, 300	March	122, 750
October	238, 650	April	286, 624
November	134, 700	May	211, 250
December	40, 300	June	252, 150
		Total for year	2, 298, 449

During the year the park has been the center of a number of scientific activities. The American Society of Mammalogists, the American Ornithologists' Union, and the Society of Ichthyologists and Herpetologists all visited the park officially and had their annual smoker at the administration building. The Vivarium Society has held monthly meetings at the park.

The attendance of organized classes of students was 27,959, from 445 different schools.

IMPROVEMENTS

The bird house was completed in June and the installation of the birds commenced, so the building will be opened to the public early in the summer. This building is unique of its kind in providing four rooms under one roof, with 145 indoor cages. The great flight cage in the center room is 58 feet long by 22 feet wide and 30 feet high, with rock work and running water at one end, a large pool in the middle, and a fine tree at the opposite end, and makes, with its contents, a remarkably fine exhibit. Mr. Harris, the District architect, and Arthur L. Smith, the contractor, deserve great credit for this building, which has been highly praised by visitors from other zoological parks and by the public in general.

Outdoor cages will be built during the coming fall, which will make the bird house the center of the ornithological section of the park. It is planned to develop the area about this building as runs for outdoor birds.

In connection with the bird house, the maintenance force of the park has done a great deal of work, cutting down a considerable hill to permit a good approach to the building, building walks and roads, installing sewers, and other details necessary to the new building, so that in general we have been able to make few improvements in other parts of the park.

NEEDS OF THE ZOO

At present a considerable part of the appropriation has to be spent each year in repairing temporary structures. (Report of June 30, 1902.)

The inadequacy of the appropriations for the proper equipment of the park has made it necessary to exercise an unwise economy in the construction of its

buildings and other shelters, the majority of which are of a cheap and temporary character, and sooner or later must be replaced. (Report of June 30, 1906.)

It should be remembered that at the inception of the park the funds provided for buildings and improvements were entirely inadequate for its proper equipment and that consequently the management was forced to construct cheap, temporary shelters, roads, walks, and inclosures. These have now arrived at about their limit of usefulness and do not admit of further economical repair. (Report of June 30, 1909.)

The buildings mentioned in the above reports are still being used.

For more than 20 years earnest, but at the same time modest, appeals have been made in each annual report for adequate housing of the animals. Our buildings have been for years a source of most unfavorable comment on the part of visitors. While other zoos throughout the United States have been improving and enlarging, the National Zoological Park, with the exception of the bird house, has been able to do almost nothing in the way of construction, so that at present, in comparison with a half dozen other American zoos, our equipment is extremely shabby. It is impossible to maintain the collection at its present status if this condition is ignored. The fine new bird house just completed is an indication of the conditions that should be provided for other animals.

To house a collection of animals properly, suitable buildings are needed, and the following building program is presented. This program is limited to strictly essential buildings:

1. Exhibition house for reptiles, amphibians, and invertebrates, with proper heating and lighting apparatus (based on cost of recent reptile houses elsewhere)	$220,000
2. Ape, lemur, and small mammal house—this to house the collection of small mammals of the world and to have a wing for the great apes	150,000
3. Pachyderm house—this to include also quarters for giraffe	250,000
4. To make permanent one wing of the carnivore house and to remodel the one wing which is of sufficient value to repair	100,000
5. Antelope, buffalo, and wild-cattle house	100,000
6. To add wing to bird house and develop areas about with open-air aviaries, pheasant and game-bird runs	100,000
7. A proper fence around the park (a high iron fence on a concrete base)	85,000
The above items are most necessary. To these should be added:	
8. Open, barless exhibition quarters for bears, lions, and tigers. Such exhibitions are most popular and some of the newer zoological parks are specializing in them. It is our desire to have only a limited number of these	80,000
9. Monkey pit—a barless, open village for monkeys	10,000

Respectfully submitted.

W. M. MANN, *Director*.

DR. CHARLES G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 7

REPORT ON THE ASTROPHYSICAL OBSERVATORY

Sir: The Astrophysical Observatory was conducted under the following passage of the independent offices appropriation act approved February 11, 1927:

> Astrophysical Observatory: For maintenance of the Astrophysical Observatory, under the direction of the Smithsonian Institution, including assistants, purchase of books, periodicals, and apparatus, making necessary observations in high altitudes, repairs and alterations of buildings, preparation of manuscripts, drawings, and illustrations, traveling expenses, and miscellaneous expenses, $32,060, of which amount not to exceed $29,000 may be expended for personal services in the District of Columbia.

The observatory occupies a number of frame structures within an inclosure of about 16,000 square feet south of the Smithsonian Administration Building at Washington, a cement observing station and frame structure for observers on a plot of 10,000 square feet leased from the Mount Wilson Observatory, and an observing station on Table Mountain, Calif. This last station, provided by Mr. John A. Roebling, includes a tunnel for instruments, small structures for the field director and for the assistant, a shop, and a garage.

The Astrophysical Observatory also defrays a part of the cost of the maintenance of the observing station at Montezuma, Chile, which was erected in 1920 with means furnished by Mr. Roebling. The constructions there comprise a tunnel for instruments, a small structure for observers, shop, garage, and a telephone line 12 miles to Calama.

The present value of the buildings and equipment for the Astrophysical Observatory owned by the Government is estimated at $50,000. This estimate contemplates the cost required to replace the outfit for the purposes of the investigations.

WORK AT WASHINGTON

(*a*) *Reduction of observations.*—Three field stations—Table Mountain, Calif., Montezuma, Chile, and Brukkaros, South West Africa—are now steadily sending results of daily observations of the intensity of solar radiation to the Smithsonian Institution. The work of comparing these observations, of detecting and determining sources of error, and correcting therefor, and the care of keeping the three stations, thousands of miles away in the wilderness, supplied with

material and personnel has occupied much time of the director and staff in Washington.

Several years having gone by since the station at Table Mountain began its regular work, enough data had accumulated to justify a statistical study over the whole period, to detect any systematic errors. Minute systematic errors in the uncorrected results are inevitable. We are attempting to determine the intensity of the sun's energy not only as it is received at the observatory but also as it was in free space outside the atmosphere. Humidity and dust produce effects which it is impossible to ascertain precisely on any given individual day by any method. Hence only by comparing the average run of the results over a term of years with the average run of atmospheric conditions during the same interval can these not quite negligible residual systematic errors be determined and allowed for. Such a study of the Table Mountain work has been in progress. When completed there were revealed certain discordances between Table Mountain and Montezuma which, though small, demanded still further study.

As so often has happened in the history of science, this study by my colleague, Mr. Fowle, of a perplexing discordance has brought a new discovery of some importance. It is that the ozone existing in the atmosphere at a level of 30 to 50 kilometers (18 to 30 miles), and which is formed from the atmospheric oxygen by the action of invisible ultra-violet sun rays, is variable in amount over Table Mountain, though nearly constant in amount over Montezuma. The discrepancy in the final results of radiation work between the two stations appears to be due mainly to this variability of atmospheric ozone at Table Mountain. Regular observations of ozone are now in progress there in cooperation with Doctor Dobson, of Oxford, England.

The tedious but necessary computations and statistical comparisons involved in the work of systematizing and correcting the preliminary results of the observations, only part of which is indicated in the discussion above, have employed Mr. Fowle and two computers continually during the year.

(*b*) *Apparatus.*—Under the direction of the writer and his colleague, Mr. Aldrich, the instrument maker, Mr. Kramer, has continued to make apparatus for radiation investigations. One instrument upon which much attention has been lavished is a new form of pyrheliometer to measure more accurately and conveniently the sun's radiation. So accurate and stable is the silver-disk pyrheliometer which we have employed for nearly 20 years, and of which over 50 copies have been furnished by the Smithsonian at cost to other institutions at home and abroad, that it is hard to prepare a new instrument superior to it. Yet there are two or three slight sources of

error, and a certain slowness of reading characteristic of the silver-disk instrument which it is hoped to improve upon. Thus far the new instrument, of a compensating electrical type, has not quite reached expectations, but it is still hoped to overcome its deficiencies and retain its advantages.

Attention was also paid to the improvement of the radiometer for measuring the energy of the spectra of the stars. In this instrument it was proposed to seal the sensitive element in a truly circular, optically figured quartz tube containing a small pressure of hydrogen, and to adjust the position and direction of the system by moving and rotating the inclosing cylinder. The device was made ready for use by the writer during the summer of 1928 at Mount Wilson, Calif., with good results, which will properly be described in next year's report.

In connection with a research by Mr. Aldrich on the radiation and convection of the normally clothed human body, a number of instrumental appliances were also made.

(*c*) *Research on the loss of heat from the human body.*—Inquiry was made of the writer by Mr. T. J. Duffield, secretary to the New York Commission on Ventilation, as to the proportion of the loss of heat of the normally clothed human body which should be ascribed to radiation rather than to convection by the air. The subject needed investigation, and at the writer's suggestion a grant of $1,000 was made by the New York Commission on Ventilation to the Smithsonian to promote it. My colleague, Mr. Aldrich, undertook the work and made several long series of novel and valuable experiments, the results of which will shortly be published. He employed principally two instruments: First, the melikeron, or honeycomb pyranometer, for observing radiation of bodies at low temperature, first described in these reports for the years 1919 and 1920; and second, a special thermoelectric temperature tester constructed for the research.

Mr. Aldrich sums up his results as follows:

(1) The radiation from the skin and clothing is approximately that of a "black body" or perfect radiator.

(2) Skin temperatures computed from melikeron radiation measurements are about 1° C. higher than skin temperatures measured directly with the thermoelement. This is not true on clothing of calorimeters. Apparently the melikeron sees deeper into the pores of the skin than the level observed by the thermoelement.

(3) A cloth-covered, vertical, cylindrical calorimeter at body temperature loses in still air 60 per cent by radiation, 40 per cent by convection. A similar horizontal calorimeter loses 54 per cent by radiation, 46 per cent by convection. The human body convection loss is probably similar to this; that is, the convection loss is roughly

one-third less than the radiation loss in still air and normal room temperatures.

(4) Increasing air motion rapidly decreases the percentage radiation loss and increases the convectional. With the vertical calorimeter:

Air motion:	Per cent radiation loss
0	60
75 feet per minute	41
130 feet per minute	35
190 feet per minute	25

(5) Total body radiation similarly decreases with air motion:

Air motion:	Radiation loss (mean for 10 subjects)
50 feet per minute	30.7 large cal. per sq. m. per hour.
50 to 100 feet per minute	29.3 large cal. per sq. m. per hour.
100 to 150 feet per minute	25.7 large cal. per sq. m. per hour.
180 to 250 feet per minute	23.2 large cal. per sq. m. per hour.

(6) Increase in room temperature (which also means increase in wall temperature) produces a progressive lowering of radiation loss. The ratio $\frac{\text{Radiation loss}}{\text{Basal metabolism}}$ decreases with increase of room and wall temperature:

Radiation loss

	Room temperature	Basal metabolism
	C.	
Table L	21°.3	0.80 (mean of 10 subjects).
	24°.1	0.75 (mean of 10 subjects).
Table J	22°.1	0.84 (mean of 3 subjects).
	24°.5	0.74 (mean of 4 subjects).
	25°.6	0.66 (mean of 3 subjects).

(7) Keeping room and wall temperatures unchanged, the temperature of the skin and clothing decreases with increasing air motion, the decrease being greatest on the side facing the wind and about one-half as great on the side away from the wind. The clothing temperature drop on the side toward the wind is about one-third greater than the corresponding skin temperature drop. Summary of 10 subjects:

Air motion (feet per minute)	Skin temperature drop		Clothing temperature drop		
	Away from wind	Toward wind	Away from wind	Toward wind	Perpendicular to wind
	C.	C.	C.	C.	C.
0 to 100	−°.4	−°.8	−°.6	−1°.3	−°.5
100 to 250	−°.7	−1°.2	−°.4	−1°.7	−°.5

(8) At normal indoor temperature, in still air and with the subject normally clothed and at rest, body heat losses are distributed as follows:

	Per cent
Evaporation of water	24
Radiation	46
Convection	30

(9) Tests with the thermoelement show that the air temperature falls to room temperature very rapidly as the distance from the body increases. That is, there is a steep temperature gradient in the first centimeter or so from the body surface. With the thermoelement 30 cm. away no effect of the presence of the body could be detected.

(10) The Abbot-Benedict work (Table A) indicates that the radiation loss from a nude subject is about twice as great for a room temperature of 15° as it is for a room temperature of 26°. This evidence does not entirely support the "suit-of-clothes" theory referred to by DuBois. In explanation of this theory, he says (p. 385, 1927 ed. Basal Metabolism): "A constriction of the peripheral blood vessels (occurs) and the amount of heat carried to the surface is relatively small in proportion to the heat produced. * * * The patient really changes his integument into a suit of clothes and withdraws the zone where the blood is cooled from the skin to a level some distance below the surface."

(11) Normal fluctuations in humidity indoors produce negligible effect upon the radiation loss. This is to be expected. Our bodies, about 300° absolute, radiate almost wholly between the wave lengths 4μ and 50μ with a maximum at 10μ. Water vapor absorption is so strong for much of this range and so nearly negligible near the maximum, that its possible effect is so fully produced, even by the humidity of an ordinary room, that the effect of changes of the quantity of water vapor in the ordinary room is small. Were the air of the room exceedingly dry, changes might be noticeable.

WORK IN THE FIELD

(*a*) *Solar radiation work at three desert mountain stations.*—As far as possible, daily measurements of the intensity of solar radiation have been made at the Smithsonian stations at Table Mountain, Calif., and Mount Montezuma, Chile. Also similar measurements have gone on regularly at the cooperating station of the National Geographic Society on Mount Brukkaros, South West Africa.

Pending completion of the statistical investigations of the results of the two last-named stations, as mentioned above, only the results obtained at Mount Montezuma are being published at present. By continued cooperation of the United States Weather Bureau, the daily

telegraphed values of the solar constant of radiation are being regularly published on the Washington daily weather map.

As tentatively and privately forecasted in November, 1927, on the basis of hitherto observed periodicities in solar phenomena, the "solar constant" values reached a high level in the spring months of 1928, and were expected to reach a low level in the autumn.[1] Much interest attaches to these tentative forecasts of the solar energy to be expected for long periods in advance, but several years must yet elapse before (if ever) they can be made with sufficient confidence to justify publication.

Although the solar radiation measurements have been reduced to a routine for several years at all our stations, the very high degree of accuracy now demanded and generally achieved is occasionally marred by new and unexpected accidents and difficulties. Thus internal evidence disclosed that some obscure error of very considerable amount began in August, 1927, to affect the sky radiation measurements of the pyranometer on Table Mountain. Our best thought and many experiments had failed to disclose the obscure cause up to the close of the period of this report, but by anticipation I may say that at this time of writing (October 3) the error has been detected, cured, and a beginning has been made to eliminate its influence from the final results of the observations. This circumstance has prevented us from making public Table Mountain results hitherto.

(*b*) *Measurements of atmospheric ozone.*—Doctor Dobson, of Oxford, England, having perfected a spectroscopic method for determining the quantity of atmospheric ozone, has found that quantity variable in most interesting relations to solar phenomena and to weather. He has established a chain of cooperating observatories in Europe, and, by aid of a grant from Mr. John A. Roebling, the Smithsonian was able to equip the Montezuma station with the necessary apparatus. For about one year daily measurements were made at Montezuma by Field Director Freeman, aided by Mrs. Freeman. The photographs taken were reduced in England by Doctor Dobson and his colleagues, but, contrary to European experience, showed almost zero variation. They also showed a much smaller quantity of atmospheric ozone at Montezuma than in Europe.

Finding further observations at Montezuma unnecessary because of the uniformly constant results, the apparatus was returned to Oxford, restandardized, and sent to Table Mountain, Calif., where it is now installed for daily observing.

(*c*) *Expeditions to Mount Wilson.*—As stated in last year's report, the writer undertook at Mount Wilson, in the autumn of 1927, to

---

[1] At this writing (October 3), this latter forecast also has been supported by September results.

continue radiometer measurements of the distribution of energy in the spectra of the stars. This work was made possible by the availability of the 100-inch telescope of the Mount Wilson Observatory. It had been proposed to substitute hydrogen for air in the radiometer, on the theory that the radiometer reaction would be nearly the same, but the damping and consequent sluggishness of action would be much diminished in so light and free-moving a gas as hydrogen.

Arriving in July, 1927, at Pasadena, the writer constructed the radiometer vanes from bits of house-flies' wings. Incidentally it was observed that it requires about 6,000,000 house-flies' wings to weigh one pound. With a fragment of microscope cover glass (ground and polished to about one-third the usual thickness) the mirror of the radiometer system was prepared. Two such systems of unequal, but both of almost microscopic size, were hung upon quartz fibers so fine as usually to be invisible, and were tested in air and in hydrogen at various pressures. With them was used also a bolometric element designed to give basis for an estimate of the comparative rise of temperature of the radiometer vanes, when exposed to a constant source of radiation, but contained in the different test gases.

Hydrogen proved somewhat less efficient in regard to rise of temperature and radiometer reaction than air, but abundantly justified the expectation that its damping properties were much less objectionable. On the whole, hydrogen appeared greatly superior as the radiometer gas, and a carefully built system, with vanes 0.35 millimeters wide and 1 millimeter tall, was constructed. It had three vanes in parallel on either side of the stem, separated 1 millimeter between centers. This system was sealed into a glass [1] case in hydrogen under 0.23 millimeter pressure of mercury. Provision had been made to rotate the system by a magnetic device.

After many trials, the device proved useless, because the mechanism required to rotate the system so as to bring it to face in the proper direction so stirred up the gas that wholly unexpected motions resulted. After much labor the experiment was given up for the year 1927.

For use in 1928, at Doctor Adams's suggestion, there was prepared an optically figured quartz cylindrical vessel. This fused quartz cylinder, of beautiful clearness, was made to my order by the General Electric Co., and was figured within and without at the Mount Wilson Observatory shop. Being truly a circular cylinder with optically figured concentric walls, it mattered not at all in what direction the radiometer looked out. Thus by mounting the whole cylinder from a

[1] I am greatly indebted to the director and staff of the Bureau of Standards, especially Mr. Sperling, and to the director and staff of the Mount Wilson Observatory, especially Mr. Pompeo, for the construction of the special glass apparatus and the preparation for its use on Mount Wilson.

brass support, rotatable in a ground joint, the radiometer could be inclosed in an airtight outside case of brass having windows, toward which the radiometer could at any time be made to look out by merely rotating the brass piece in its well-ground seat.

With this simple but adequate apparatus the Mount Wilson expedition was renewed by the writer in 1928, with a high degree of success, which must be related in next year's report.

Personnel.—During the year the personnel has been as follows:

At Washington:
- *Director*, Dr. C. G. Abbot.
- *Research assistants*, F. E. Fowle, Jr., L. B. Aldrich.
- *Temporary assistant*, M. K. Baughman.
- *Computers*, Mrs. A. M. Bond, Miss M. A. Marsden.
- *Instrument maker*, A. Kramer.

At Table Mountain:
- *Field director*, A. F. Moore.
- *Field assistants*, H. H. Zodtner, H. B. Freeman.[1]

At Mount Montezuma:
- *Field directors*, H. B. Freeman, H. H. Zodtner.
- *Field assistants*, E. E. Warner, M. K. Baughman.

At Mount Brukkaros:
- *Field director*, W. H. Hoover.
- *Field assistant*, F. A. Greeley.

Summary.—A novel research on the relative cooling of the human body by radiation and by air convection has yielded unexpected and valuable results. Improvements in instruments include a new form of sensitive radiometer in which by the substitution of hydrogen for air a great increase in quickness of response permits the use of excessively light systems and promises a great development of sensitiveness. Continued progress in the reduction and systematization of the results of solar radiation work have brought the study of the ozone content of the atmosphere as a new element in the determination of the solar constant of radiation. Daily observations have been continued at Table Mountain, Calif., Mount Montezuma, Chile, and (in cooperation with the National Geographic Society) at Mount Brukkaros, South West Africa. By cooperation with the United States Weather Bureau, daily publication of the values of the solar constant of radiation for the use of meteorologists has been effected.

C. G. Abbot,
Director, Astrophysical Observatory.

The Secretary,
The Smithsonian Institution.

[1] Mr. Freeman assisted for a short time after his return from South America, pending other assignment.

APPENDIX 8

REPORT ON THE INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE

Sir: I have the honor to submit herewith the following report on the operations of the United States Regional Bureau of the International Catalogue of Scientific Literature for the fiscal year ending June 30, 1928:

Since actual publication of the International Catalogue was suspended in 1922, owing to the inability of the foreign bureaus to contribute their quota of the necessary financial support, it has been the policy of this bureau to keep its expenditures at the lowest possible amount consistent with the need of keeping the organization operating sufficiently to compile the necessary records of current scientific publications. This policy has been explained each year to the Bureau of the Budget and to congressional appropriation committees, the understanding being that until publication was resumed some part of the appropriation would revert to the surplus fund of the Treasury. Each year a surplus has reverted, and this year it was found possible to allow the classifier to take seven months' furlough without seriously interfering with the necessary routine. By this means an additional saving of $1,225 was made, the gross expenditures of the year being $5,867.29 out of the appropriation of $7,260, the remainder, $1,392.71, reverting to the Treasury.

As the financial status of a number of the cooperating foreign countries now appears to be established on a firmer basis than at any time since the war, this bureau is making an effort, through correspondence, to formulate a practical plan whereby the necessary support may be had to enable the Central Bureau to resume publication. To this end letters were sent to the several members of the executive committee of the catalogue and to the director of the London Central Bureau in whose hands control of the organization is vested. As these letters outline the situation and are self-explanatory, I submit copies herewith.

May 22, 1928.

Dear Sir: As a member of the executive committee of the International Catalogue of Scientific Literature, to which the International Convention in Brussels in July, 1922, referred the question of the future of the undertaking, I beg to submit the following:

Among the resolutions adopted, 4 and 5 read as follows:

(4) That the convention is of opinion that the international organization should be kept in being through mutual agreement to continue as far as possible the work of the regional bureaus until such time as it may be economically possible to resume publication.

(5) That it be referred to the executive committee to consider and, after full consultation with interested bodies, to make proposals as to the form of future publication and to report with some definite scheme to a meeting of the international council, to be summoned as soon as it appears possible that publication can be resumed.

From the implied agreement in resolution 4, I assume that the organization may still look to the regional bureaus to take up again their former work when called on by the central bureau to do so, and from resolution 5 it is clearly the duty of the executive committee to formulate a definite scheme as soon as it appears possible that publication can be resumed.

As a preliminary step to the preparation of such a scheme an exchange of views by correspondence among the several members of the executive committee seems desirable, in order that all local and personal ideas may be assembled and coordinated before summoning a meeting of the international council.

Among the questions which might be satisfactorily settled through correspondence are the following:

To what extent could the central bureau depend on each regional bureau (1) to supply classified data and (2) to secure subscriptions for the support of the Catalogue.

Could an edition of 1,000 sets be disposed of at $50 per set?

Could a catalogue aggregating 10,000 pages be produced for $50,000 per year?

I am of the opinion that this sum would be sufficient, and submit with this copies of two letters sent to Doctor Morley and Professor Armstrong on January 12, 1928, outlining the present condition as I see it and giving an estimate of the probable cost of publication.

I would appreciate detailed suggestions which would further in any way our common aim and, as I think, duty to prepare and report a definite scheme whereby this unique and valuable international work may be enabled to resume publication.

I am most anxious also to have such a definite and well-considered plan available to submit to possible donors, should any appear, before a meeting of the international council is held.

Trusting that this move may meet with your approval and gain your cooperation, I am

Sincerely yours,

LEONARD C. GUNNELL.

JANUARY 12, 1928.

DR. H. FORSTER MORLEY,

Director, International Catalogue of Scientific Literature,

London, England.

DEAR DOCTOR MORLEY: I am sending with this a copy of a letter sent to-day to Professor Armstrong and trust that you and he will be able to outline some plan of action whereby the Catalogue may again be published. With 10,000 pages to be printed each year, or about 33 pages per day of printed matter that could be made simple and uniform in character, I believe that the organization could profitably run a plant of its own and issue classified cards, or advance sheets, of the material to be later assembled and published in annual catalogues.

* * * I have just consulted a practical printer and he states that our requirements could be met with two typesetting machines and one high-grade press, costing approximately a total of $10,000. * * * I believe the whole yearly cost of printing could be met for $17,500. These are American estimates and the cost should be materially less in England, but even this figure is half the estimated cost at $3.50 per page. Although the figures are necessarily only approximate they are encouraging enough to warrant looking into the matter in detail. With your central bureau and printing plant under one roof the organization would certainly be in a position to overcome the most serious faults charged against the Catalogue, high price, and delayed publication.

I did not want to complicate my letter to Professor Armstrong, but the cost of production is the only really serious question to confront us for there is no question in my mind as to the need of the Catalogue, and as we produced it once we can produce it again. Every dollar cut from the subscription price will, without doubt, increase the number of subscribers, therefore I am most anxious to get your opinion of this phase of the problem. Editing, assembling, and printing in our case is a question of uniform and continuous production and can certainly be greatly simplified and cheapened if we consider it in that light.

With kindest regards, I am

Sincerely yours,

LEONARD C. GUNNELL.

JANUARY 12, 1928.

Prof. HENRY E. ARMSTRONG,

Chairman, Executive Committee International Catalogue of Scientific Literature, Royal Society of London, London, England.

DEAR PROFESSOR ARMSTRONG: I feel that if the International Catalogue is ever to resume publication some definite steps should be taken looking to that end. Assuming that the agreement made by the delegates at the Brussels convention of 1922 to keep the organization in being is still in force, the question of resumption is in the hands of the executive committee named at that time and authorized to report with some definite scheme. As I am one of that committee, of which you are the chairman, I feel that any steps I might take, after consulting you, in an attempt to forward the interests of the Catalogue would be within my province and can be taken quite independently of the Smithsonian Institution, which need not appear in the matter until some assurance of success is evident.

The situation as I see it is: That the International Catalogue of Scientific Literature, to supply an authors' and classified subject catalogue of the current literature of pure science, is as much a necessity now as it was in 1900, since no similar service or publication has taken its place.

That the organization still exists duly authorized to prepare and publish such a catalogue.

That the enterprise can be made self-supporting if financial support sufficient to cover one year's editorial and printing expenses can be procured.

That if an edition of 1,000 sets can be sold at $50 a set the publication costs can be covered.

I am led to this opinion by the fact that a prominent American publisher has offered, if furnished regularly with manuscript to fill 10,000 pages of printed matter, to print, publish, and bind, in paper, an edition of 1,000 for $3.50 a page, or $35,000. Adding $15,000 as the approximate cost of a central bureau staff, the total would be $50,000 needed for an edition of 1,000. I believe that regular subscribers to take this edition of 1,000 sets could be readily enrolled at a price of $50 per set and the organization would thus become self-supporting. I assume

that if American publishers could print the Catalogue for $3.50 per page, in an edition of 1,000, some English printer would do the work for that sum or less.

Before any financial aid could be reasonably applied for the "definite scheme," which the executive committee was authorized to prepare, would have to be submitted, and I think that it is time for the committee to take some action.

A definite scheme could be prepared after taking the matter up with the regional bureaus and determining the probable support each could be depended on to provide in material for the Catalogue and subscribers. It would then be necessary to prepare revised schedules of classification and lists of journals to be indexed. From previous experience I am sure that you will agree with me that the schedules should be far more simple than those previously used and that the journals and papers indexed should be limited strictly to pure science, else the whole undertaking would be too ponderous at the very beginning. I feel that after a start has been made an allied though supplementary index of the applied sciences would be feasible and certainly most desirable, but this could not be attempted until the more simple index to pure science is provided and put on a paying basis. What in your opinion would be the attitude of the Royal Society and the Zoological Record?

The plan published in the acta of the convention of 1922 included disposal of the stock of complete sets at a reduced price, when publication should be resumed, as a means of repaying the debt to the Royal Society, and this plan would still hold.

With kindest regards, I am

Sincerely yours,

LEONARD C. GUNNELL.

While it is as yet too soon to forecast what the result of this move toward reorganization will be, it seems probable that the various countries previously represented will again cooperate by furnishing the necessary bibliographical data to the central bureau, but it is doubtful if they are in a position to subscribe to the capital fund necessary to start the operations of the central bureau.

The French bureau's reply, dated June 22, 1928, seems to bear out this idea, the reply stating: "If therefore the Catalogue were resumed we could immediately furnish everything relating to France." The French bureau, however, could promise nothing toward the support of the central bureau, but has requested the director of public instruction to canvass the French universities for subscribers.

If during the coming year a definite scheme can be agreed upon by the countries formerly cooperating in the work, it appears likely that the comparatively small sum needed to begin publication could be raised in the United States. It would appear both fitting and proper to have aid extended from this country to reestablish a great and useful enterprise originally founded on the idea and suggestion of an American pioneer in science, Joseph Henry, first secretary of the Smithsonian Institution.

Respectfully submitted.

LEONARD C. GUNNELL,
Assistant in Charge.

DR. CHARLES G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 9

REPORT ON THE LIBRARY

SIR: I have the honor to submit the following report on the activities of the library of the Smithsonian Institution for the fiscal year ended June 30, 1928:

THE LIBRARY

The Smithsonian library, or, more properly speaking, the Smithsonian library system, comprises the Smithsonian deposit in the Library of Congress, which is the main library of the Institution, the library of the United States National Museum, the Smithsonian office library, the Langley aeronautical library, the technological library, and the libraries of the Astrophysical Observatory, the National Gallery of Art, the Freer Gallery of Art, and the National Zoological Park, together with the 36 sectional libraries of the National Museum. To these may later be added a tenth divisional library, namely, that of the Bureau of American Ethnology. With its 700,000 volumes, pamphlets, and charts, chiefly scientific in character, including especially society and serial publications, the Smithsonian library not only is an invaluable instrument in the work of the Institution and indirectly of other research institutions throughout the country, but represents an important link in the chain of libraries in the service of the Federal Government.

THE STAFF

It is gratifying to report that during the last fiscal year a way was found of providing for a second position of assistant librarian—the first, that of chief of the reference department, having been established two years before. This new position will be set up immediately and will be filled by the appointment of a chief for the accessions department—the department which acquires publications for the library, partly by purchase and gift but mainly by exchange; which carries on an extensive correspondence, particularly with the learned societies and institutions of the world, keeps a file of this correspondence and a record of the items acquired, with their sources, and assigns them to the divisions and sections of the library in which they promise to be of most use.

Several changes occurred in the personnel during the year. Mrs. Natalie M. Bennett, junior librarian, resigned and her place was filled by the appointment of Miss Gertrude L. Woodin, a graduate of Wellesley College and of the Albany Library School, who has had many years of experience in library work. Miss Woodin is directing the preparation of the union catalogue. Mr. R. Webb Noyes, junior librarian, also resigned and was succeeded by Miss Elisabeth Hobbs, a graduate of George Washington University and of Simmons College Library School. At various times during the year the following persons were members of the staff on temporary appointment: Miss Helen V. Barnes, Mrs. Adella E. Blanchard, Mr. Arthur W. Gerth, Miss Elisabeth Hobbs, Miss Josephine H. Kinney, Miss Mary Ladd, Mrs. M. Landon Reed, Mrs. Hope H. Simmons, and Mr. Giles E. Taggart.

EXCHANGE OF PUBLICATIONS

Since its founding in 1846 the Smithsonian Institution and its branches as one by one they have come into being have sent their publications to other learned institutions and societies and to editors of scientific journals throughout the world, and have received their publications in return. Although from the beginning the increase of the Smithsonian library has been due partly to purchases and gifts, it has been due chiefly to this exchange. These publications have come to the library direct, or through the International Exchange Service, which is administered by the Institution. During the last fiscal year 26,316 packages, of one or more publications each, came by mail, and 6,231 through the exchange. After these 32,547 packages had been opened the items were stamped, entered, and sent to the appropriate units of the library, but chiefly to the Smithsonian deposit in the Library of Congress and the library of the United States National Museum. In connection with the acquiring of this material the library wrote about 1,100 letters, sent out thousands of acknowledgments, and took up exchange relations with many new societies.

As usual dissertations were received from various universities and technical schools both at home and abroad.

GIFTS

The gifts for the year were many. Two were especially noteworthy. One was the Chinese library of the late Hon. William Woodville Rockhill, well-known traveler, scholar, and United States minister to China. This was presented to the Institution by Mrs. Rockhill, and was deposited in the Freer Gallery of Art. It consisted of 1,100 volumes on the history, geography, literature, and

culture of Central Asia, particularly of Mongolia and Thibet, and included a number of rare items, several in manuscript, and various works of general reference, among which was a copy of the Palace Edition of the Imperial Dictionary issued in 1716 in 40 volumes by a commission of scholars under the personal supervision of Emperor K'ang Hsi. This gift constitutes a most valuable supplement not only to the Chinese works in the library of the Freer Gallery but to those in the oriental division of the Library of Congress.

The other noteworthy gift came from the American Association for the Advancement of Science. It comprised approximately 3,500 volumes of serial and society publications, from all parts of the world and in nearly all languages, many in almost unbroken sets extending over years. From this collection have already been selected more than 1,500 volumes and parts needed in the Smithsonian deposit and the libraries of the National Museum and the Astrophysical Observatory. Among these were some that were out of print and very rare, including not a few that these libraries had been trying for some time to get to complete their sets. The gift is one of the most useful that the library has received in recent years.

Among other gifts worthy of especial mention were scientific publications in 68 volumes and 47 parts, lacking in the Smithsonian library, from the Library of Congress; North American Wild Flowers, volumes 1 to 3, by Mary Vaux Walcott, from the artist-author; a collection of 70 volumes and 174 pamphlets, mainly on art, from Dr. William H. Holmes, director of the National Gallery; various works, in 50 volumes, chiefly on Egyptian art and archeology, from Mrs. George Cabot Lodge; To Galápagos on the Ara, 1926, by William K. Vanderbilt, from the author; A Souvenir of Wyoming—an illustrated manuscript in 3 volumes, with text by John G. White, being a diary of a fishing trip in Jackson Hole and Yellowstone Park, with remarks on early history and historical geography—from Thomas A. McCaslin; the Ronald Aeronautic Library, in 12 volumes, presented by the publishers at the suggestion of Mr. Paul E. Garber, assistant curator of the divisions of mineral and mechanical technology; and about 300 volumes, pertaining largely to the religions of the Old World, from the estate of Dr. I. M. Casanowicz, late assistant curator of the division of Old World archeology.

Many other gifts were also received, especially from Secretary Abbot, Assistant Secretary Wetmore, Mr. A. H. Clark, Dr. Walter Hough, Dr. Aleš Hrdlička, Dr. W. R. Maxon, Mr. J. U. Perkins, Miss M. J. Rathbun, Dr. C. W. Richmond, Mr. Robert Ridgeway, the late Dr. J. N. Rose, Mr. R. C. Smith, Dr. L. Stejneger, Mr. B. H. Swales, and Dr. J. R. Swanton.

SMITHSONIAN DEPOSIT

The Smithsonian deposit, which, as has been said, is the main library of the Institution, dates from 1866, when by an act of Congress the Institution was authorized to deposit its library of 40,000 volumes in the Library of Congress. It is, of course, distributed according to classification, but because of its prevailingly scientific nature it is chiefly in the Smithsonian division, which was established in 1900 to take care of the scientific publications in the deposit, together with the works of like character belonging to the Library of Congress.

The deposit has grown steadily by additions from the Institution, and is now recognized as one of the outstanding collections of its kind. It is especially rich in serial publications and in the reports, proceedings, and transactions of the learned societies and institutions of the world.

During the fiscal year just ended the Institution sent to the deposit 13,558 publications, of which 2,292 were volumes, 9,773 parts of volumes, 988 pamphlets, and 505 charts. Documents of foreign governments, largely statistical in character, to the number of 7,376, were also sent, without being stamped or entered, to the document division of the Library of Congress. In addition to these, 13,187 dissertations, most of which had been received in previous years from forty or more universities and technical schools in different parts of the world, but which the Institution, for lack of help, had not been able to catalogue, were forwarded to the deposit, that they might be made available to scholars at the earliest possible moment. Short title cards for these dissertations will be sent to the Institution as soon as they are prepared for filing in the union catalogue.

In response to special requests from the Library of Congress for publications wanted for the deposit, the Smithsonian library was able to obtain, as usual, many volumes and parts of volumes by exchange. It is expected that this service will be greatly enlarged in the course of a few months, as the result of the reorganization of the accessions department of the library.

OFFICE LIBRARY

The office library consists of some of the more important society publications that the Institution needs to have continually at hand, a set of its own publications and of those of its branches, the art-room collection, the employees' library, and various reference books, some assigned for special use to other divisions of the library or to the administrative offices of the Institution. To this library were added during the year 108 volumes and 34 pamphlets.

The progress made on the union catalogue of the Smithsonian library, which was kept until lately in the office reading room—the room that now has become the catalogue room of the Institution—was notable, especially in connection with the material in the Smithsonian deposit, the office library, the Langley aeronautical library, and the libraries of the National Museum and the Astrophysical Observatory. Cards were also added to the catalogue for the Rockhill collection of 1,100 volumes in Chinese recently given to the Institution and deposited in the library of the Freer Gallery of Art. This progress is shown in detail by the following statistics:

Volumes catalogued	3,137
Volumes recatalogued	3,913
Pamphlets catalogued	1,766
Pamphlets recatalogued	2,846
Charts catalogued	504
Typed cards added to catalogue	3,337
Library of Congress cards added to catalogue	6,372

MUSEUM LIBRARY

The library of the United States National Museum, which ranks next in size and importance to the Smithsonian deposit in the library system of the Institution, is composed principally of works on the different branches of natural history represented in the Museum. Its collections increased during the year by 3,015 volumes and 1,165 pamphlets, totaling more by several hundred than the increase even of the year before when there was an unusually large gain in accessions. The library now numbers 72,315 volumes and 106,881 pamphlets. Some of the additions came, of course, by purchase, but most came, as usual, by exchange and gift. The outstanding gift, which, with other gifts to various divisions of the library of the Institution, is described earlier in this report, was received from the American Association for the Advancement of Science.

In the course of the year 10,526 parts of periodicals were entered, 821 volumes and 1,039 pamphlets were catalogued, and 2,382 cards were added to the shelf list. The number of books and pamphlets sent to the sectional libraries was 6,683. The loans to members of the scientific staff numbered 5,013, of which 2,113 were borrowed from the Library of Congress and 236 elsewhere. The other loans totaled 89. These were made chiefly to Government libraries, but a score or more to libraries outside of Washington, including those of the American Museum of Natural History, Archeological Institute of America, Berkshire Atheneum, Carnegie Museum, E. I. du Pont de Nemours & Co. Experimental Station, Rockefeller Institute, Westfield Normal School, Williams College, and the following universities: Maryland, North Carolina, Princeton, and Toronto. The number of

books sent back to other libraries was 2,451, of which 2,262 were returned to the Library of Congress. The volumes prepared for binding numbered nearly 2,200; of these 1,701 were sent to the bindery during the fiscal year. As usual, thousands of publications were consulted in the reading room, not merely by members of the Museum staff, but by investigators from other departments of the Government and elsewhere, including some from abroad. In connection with their work an increased reference service was rendered by the library staff, as was the case in connection with the many inquiries for information that were received from different parts of the country.

The sectional libraries, which now number 36, were brought into closer working relation with the main library of the Museum and with the other units of the Smithsonian library system. The work of completing their sets of society and serial publications was continued, their binding was considerably advanced, and marked progress was made in cataloguing their collections. The sectional libraries are as follows:

Administration.
Administrative assistant's office.
American archeology.
Anthropology.
Biology.
Birds.
Botany.
Echinoderms.
Editor's office.
Ethnology.
Fishes.
Foods.
Geology.
Graphic arts.
History.
Insects.
Invertebrate paleontology.
Mammals.
Marine invertebrates.
Mechanical technology.
Medicine.
Minerals.
Mineral technology.
Mollusks.
Old World archeology.
Organic chemistry.
Paleobotany.
Photography.
Physical anthropology.
Property clerk's office.
Reptiles and batrachians.
Superintendent's office.
Taxidermy.
Textiles.
Vertebrate paleontology.
Wood technology.

TECHNOLOGICAL LIBRARY

The reorganization of the technological library, which is housed in the Arts and Industries Building, received particular attention. Many thousands of Government publications not related directly to the work of the institution and its branches, which had been accumulating in the library for years, were returned to the Superintendent of Documents, thus releasing space for the much needed rearranging and expanding of the collections now going on. The most noticeable change was made in the reference room. The cement floor was covered with a cork carpet, many new shelves were built in, some of the furniture was done over, and, to make the room still more

attractive, several ferns, palms, and other plants—the generous gift of the Bureau of Plant Industry—were placed on the floor and in the gallery. The collections in this room were entirely reorganized, the less used books being removed to other parts of the library, and those in constant demand by the curators put where they would be immediately available. Among the latter were the standard reference works that belong to the library and a set of Smithsonian publications. To this room were also transferred from the Smithsonian Building the current files of scientific and popular periodicals, and the employees' library. Finally, a trained assistant was put in charge, and the room opened to the public, with the result that the library increased its usefulness many fold, not only by making its collections more accessible to the curators, but by providing material and information, both directly and indirectly, for the readers and other visitors who came to it daily.

The accessions for the year are included among those to the Museum library.

ASTROPHYSICAL OBSERVATORY LIBRARY

The library of the Astrophysical Observatory, which occupies part of the main hall of the Smithsonian Building and part of the observatory itself, comprises about 3,767 volumes and 2,725 pamphlets, chiefly on astrophysics and meteorology. It is one of the most important of the smaller units of the Smithsonian library system, and is of especial value in connection with the well-known researches in solar radiation that are being carried on by the Institution. During the past year the catalogue for this library, which was begun the year before, was finished, and the collections were labeled and rearranged. The accessions to the library were 130 volumes, 64 parts of volumes, and 25 pamphlets. The number of volumes bound was 121.

BUREAU OF AMERICAN ETHNOLOGY LIBRARY

The library of the Bureau of American Ethnology, which is in the Smithsonian Building, consists almost exclusively of works on anthropology, particularly those pertaining to the American aborigines, and covers especially the linguistics, history, archeology, myths, religion, arts, sociology, and general culture of the American Indian. It contains 27,921 volumes and 16,177 pamphlets. In its special data files are manuscript material, photographs, Indian vocabularies, etc. The activities of this library for the last fiscal year are described in the report of the chief of the bureau, by whom the library is administered.

LANGLEY AERONAUTICAL LIBRARY

The Langley aeronautical library, as the aeronautical collection of the Institution is now called, is rapidly coming to be a prominent division of the Smithsonian library. While it is still comparatively small, numbering only 1,612 volumes and 700 pamphlets, together with a large number of photographs and newspaper clippings, it includes many rare items, some of which were in the original gift as it came from Samuel Pierpont Langley, the third secretary of the Institution, after whom the library was named, and others among the additions made since by Alexander Graham Bell, Octave Chanute, and James Means. During the last year the recataloguing of this library was begun, and well advanced. The accessions were 12 volumes. Much use was made of the collection, especially by Government experts and others from different parts of the United States and Europe, who were investigating matters of aeronautical interest.

NATIONAL GALLERY OF ART LIBRARY

The library of the National Gallery of Art, which occupies for the present part of the Natural History Building, concerns itself chiefly with the art of the United States and Europe. The collection, while small, totalling only 848 volumes and 1,024 pamphlets, constitutes a carefully chosen nucleus for the larger library that will be formed when a special building is provided for the gallery. The library was increased during the last year by 144 volumes, 714 parts of volumes, and 238 pamphlets. The most important gift was received from Dr. William H. Holmes, director of the gallery. This is mentioned in more detail earlier in this report.

FREER GALLERY OF ART LIBRARY

The library of the Freer Gallery of Art holds a unique place in the Smithsonian library system. It contains many works in the Chinese and Japanese languages, some of which are very rare, and for purposes of research supplements to an important degree the oriental division of the Library of Congress. It has to do mainly with the interests represented by the collections of art objects pertaining to the arts and cultures of the Far East, India, Persia, and the nearer East; by the life and works of James McNeill Whistler and of certain other American painters whose pictures are owned by the gallery; and, further, to a very limited extent, by the Biblical manuscripts of the fourth and fifth centuries, which, as the possession of the Freer Gallery, are known as the Washington manuscripts. Additions to the library during the year numbered 1,126

volumes and 59 pamphlets. These included the William Woodville Rockhill collection of 1,100 volumes in Chinese, which was given to the Smithsonian Institution by Mrs. Rockhill and deposited in the library of the gallery. This valuable gift is described elsewhere in this report. The library now has a total of 4,038 volumes and 2,578 pamphlets. It also has a special collection of about 700 volumes and 500 pamphlets for the use of the field staff of the gallery.

NATIONAL ZOOLOGICAL PARK LIBRARY

The library of the National Zoological Park, which is housed in the administration building at the park, consists of about 1,200 volumes and 300 pamphlets on animals and other subjects of special interest to the curators there. Its accessions during the last year were 11 volumes and 2 pamphlets.

SUMMARY OF ACCESSIONS

The accessions for the year, with the exception of those to the library of the Bureau of American Ethnology, may be summarized as follows:

Library	Volumes	Pamphlets and charts	Total
Astrophysical Observatory	130	25	155
Freer Gallery of Art	1,126	59	1,185
Langley aeronautical library	12	----------	12
National Gallery of Art	144	238	382
National Zoological Park	11	2	13
Smithsonian deposit, Library of Congress	2,292	14,680	16,972
Smithsonian office	108	34	142
United States National Museum, including the technological library	3,015	1,165	4,180
Total	6,838	16,203	23,041

The estimated number of volumes, pamphlets, and charts in the Smithsonian library, not including those in the library of the Bureau of American Ethnology, on June 30, 1928, was as follows:

Volumes	527,941
Pamphlets	156,983
Charts	24,660
Total	709,584

This number does not include the many thousands of volumes in the library still uncatalogued or awaiting completion.

SPECIAL ACTIVITIES

It was possible for the staff to undertake a number of special tasks during the year, several of which may be mentioned.

One of the larger accumulations of reprints was sorted according to subject and distributed to the curators. This was an important step in disposing of material valuable to the Institution but not needed for cataloguing. As soon as help becomes available another accumulation, much larger than the first, will be treated in like manner.

A list was made, in preparation for cataloguing, of some of the special collections, including the Casey, Dall, Gill, Henderson, Lacoe, Roebling, Schaus, Springer, Teller, and Vaux, and of the volumes in the John Donnell Smith botanical collection and the Watts de Peyster library that had not already been catalogued. To expedite this work the Library of Congress was generous enough to contribute for a few weeks the services of two typists, in return for which the Smithsonian library will later provide manuscript cards for the items in these collections, as well as in its other collections, that are not in the library of Congress. These cards will be prepared primarily for the national catalogue that is in progress there under the direction of Dr. Ernest C. Richardson, consultant in bibliography and research.

The generous contribution of material (see "Gifts," p. 124) that was received during the year from the American Association for the Advancement of Science was carefully checked up and many of the items were selected to fill gaps in the sets of serial and society publications. The rest of the contribution will be used in various ways later.

Most of the uncatalogued Russian publications were looked over and those with Roman titles were entered in the catalogue; the rest were put aside, to be sent, with other publications in Russian, Turkish, and Japanese, and probably some in Hungarian, Polish, and Bohemian, to the Smithsonian deposit, that they may be made available to scholars, and cards prepared for them in due course and returned to the Institution.

The organization of the west stacks in the Smithsonian Building was considerably advanced. Many thousands of college and university publications, not needed by the library, were sent to the Bureau of Education, where they would be at hand for completing sets and for exchange. The files of popular and semipopular periodicals, which had for many years been kept in these stacks, were transferred, through the courtesy of the curator of textiles, to a room in the basement, to await final disposal. The geological material was brought together and arranged. The publications that lay in heaps on the floors were grouped roughly on the shelves. This work was all preliminary to the final step in organizing this heterogeneous mass, which contains almost countless items of value, many of which,

it will probably be found later, will serve a purpose either in the library of the Institution or in other Washington libraries. Those that will not, will be used for exchange toward further completing the Smithsonian collections.

During the year the librarian gave 14 public lectures and addresses, 2 on the Smithsonian Institution, the others on literary and educational subjects. In addition to his three regular reports, namely, to the Secretary of the Institution, the Assistant Secretary in charge of the National Museum, and the Librarian of Congress, he prepared for the Secretary two special reports, entitled, respectively, "The Smithsonian Library—an Interpretation" and "Accomplishments of the Smithsonian Library, 1924–1928." In connection with the latter he checked up and listed the special collections in the library. He also contributed descriptions of the various libraries in the Smithsonian library system to the "Handbook of Washington's Informational Resources"—a recently published directory of libraries in the District of Columbia; and prepared a bibliography of significant works in American history and literature for one of the French colleges.

Respectfully submitted.

William L. Corbin, *Librarian.*

Dr. Charles G. Abbot,
Secretary, Smithsonian Institution.

24034—29——10

APPENDIX 10

REPORT ON THE PUBLICATIONS

SIR: I have the honor to submit the following report on the publications of the Smithsonian Institution and the Government bureaus under its administrative charge during the year ending June 30, 1928:

The Institution proper published during the year 11 papers in the series of Smithsonian Miscellaneous Collections, 1 annual report, and pamphlet copies of the 31 articles contained in the report appendix, and 4 special publications. The Bureau of American Ethnology published one annual report and one bulletin. The United States National Museum issued 1 annual report, 3 volumes of proceedings, 5 complete bulletins, 2 parts of a bulletin, 1 complete volume in the series Contributions from the United States National Herbarium, and 57 separates from the proceedings.

Of these publications there were distributed during the year 183,196 copies, which included 102 volumes and separates of the Smithsonian Contributions to Knowledge, 26,099 volumes and separates of the Smithsonian Miscellaneous Collections, 29,720 volumes and separates of the Smithsonian Annual Reports, 5,783 Smithsonian special publications, 111,405 volumes and separates of the various series of National Museum publications, 9,126 publications of the Bureau of American Ethnology, 178 publications of the National Gallery of Art, 28 volumes of the Annals of the Astrophysical Observatory, 42 reports of the Harriman Alaska Expedition, and 713 reports of the American Historical Association.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

Of the Smithsonian Miscellaneous Collections, volume 78, the title-page and table of contents, was issued; volume 79, one paper (whole volume) and title-page and table of contents; and volume 80, 10 papers and title-page and table of contents, as follows:

VOLUME 78

Title-page and table of contents. (Publ. 2920.)

VOLUME 79

World Weather Records. Collected from official sources by Dr. Felix Exner, Dr. G. C. Simpson, Sir Gilbert Walker, H. Helm Clayton, and Robert C. Moss-

man. Assembled and arranged for publication by H. Helm Clayton. Published under grant from John A. Roebling. August 22, 1927. vi+1,199 pp. (Publ. 2913.) (Whole volume.)

Title-page and table of contents. (Publ. 2918.)

VOLUME 80

No. 3. Fossil Footprints from the Grand Canyon: Second Contribution. By Charles W. Gilmore. July 30, 1927. 78 pp., 21 pls., 37 text figs. (Publ. 2917.)

No. 4. Religion in Szechuan Province, China. By David Crockett Graham. February 4, 1928. 83 pp., 25 pls., 16 text figs. (Publ. 2921.)

No. 5. Drawings by A. De Batz in Louisiana, 1732–1735. By David I. Bushnell, jr. December 1, 1927. 14 pp., 6 pls. (Publ. 2925.)

No. 6. Yakṣas. By Ananda K. Coomaraswamy. May 8, 1928. 43 pp., 23 pls. (Publ. 2926.)

No. 7. The Aboriginal Population of America North of Mexico. By James Mooney. February 6, 1928. 40 pp. (Publ. 2956.)

No. 8. Fossil Footprints from the Grand Canyon. Third Contribution. By Charles W. Gilmore. January 28, 1928. 16 pp., 5 pls., 7 text figs. (Publ. 2956.)

No. 9. Aboriginal Wooden Objects from Southern Florida. By J. Walter Fewkes. March 26, 1928. 2 pp., 3 pls. (Publ. 2960.)

No. 10. Drawings by John Webber of Natives of the Northwest Coast of America, 1778. By David I. Bushnell, jr. March 24, 1928. 12 pp., 12 pls. (Publ. 2961.)

No. 11. The Legs and Leg-bearing Segments of Some Primitive Arthropod Groups, with Notes on Leg-segmentation in the Arachnida. By H. E. Ewing. April 23, 1928. 41 pp., 12 pls. (Publ. 2962.)

No. 12. Charles Doolittle Walcott, Secretary of the Smithsonian Institution, 1907–1927. Memorial Meeting, January 24, 1928. May 12, 1928. 37 pp., 1 pl. (Publ. 2964.)

Title-page and table of contents. (Publ. 2969.)

SMITHSONIAN ANNUAL REPORTS

Report for 1926.—The complete volume of the Annual Report of the Board of Regents for 1926 was received from the Public Printer October 4, 1927.

Annual Report of the Board of Regents of the Smithsonian Institution, showing operations, expenditures, and condition of the Institution for the year ending June 30, 1926. xii+551 pp., 125 pls., 21 text figs. (Publ. 2879.)

The appendix contained the following papers:

The New Outlook in Cosmogony, by J. H. Jeans.

Influences of Sun Rays on Plants and Animals, by C. G. Abbot.

On the Evolution of the Stars, by C. G. Abbot.

Excursions on the Planets, by Lucien Rudaux.

High Frequency Rays of Cosmic Origin, by R. A. Millikan.

The Present Status of Radio Atmospheric Disturbances, by L. W. Austin.

Cold Light, by E. Newton Harvey.

Scientific Work of the Maud Expedition, 1922–1925, by H. U. Sverdrup.

The Romance of Carbon, by Arthur D. Little.

The Cause of Earthquakes: Especially Those of the Eastern United States, by William Herbert Hobbs.

The Loess of China, by George B. Barbour.

A Visit to the Gem Districts of Ceylon and Burma, by Frank D. Adams.

The History of Organic Evolution, by John M. Coulter.

Barro Colorado Island Biological Station, by Alfred O. Gross.

Geography and Evolution in the Pocket Gophers of California, by Joseph Grinnell.

How Beavers Build Their Houses, by Vernon Bailey.

The Mosquito-Fish (*Gambusia*), and Its Relation to Malaria, by David Starr Jordan.

The Effect of Aluminum Sulphate on Rhododendrons and Other Acid-Soil Plants, by Frederick V. Coville.

Eastern Brazil through an Agrostologist's Spectacles, by Agnes Chase.

Our Heritage from the American Indians, by W. E. Safford.

The Parasite Element of Natural Control of Injurious Insects and Its Control by Man, by L. O. Howard.

Fragrant Butterflies, by Austin H. Clark.

The Ritual Bullfight, by C. W. Bishop.

The Bronzes of Hsin-Chêng Hsien, by C. W. Bishop.

The Katcina Altars in Hopi Worship, by J. Walter Fewkes.

Omaha Bow and Arrow-Makers, by Francis La Flesche.

The National Park of Switzerland, by G. Edith Bland.

Samuel Slater and the Oldest Cotton Machinery in America, by Frederick L. Lewton.

Preventive Medicine, by Mark F. Boyd.

William Bateson, by T. H. Morgan.

H. Kamerlingh Onnes, by F. A. Freeth.

Report for 1927.—The report of the executive committee and proceedings of the Board of Regents of the Institution, and the report of the acting secretary, both forming parts of the annual report of the Board of Regents to Congress, were issued in December, 1927.

Report of the Executive Committee and Proceedings of the Board of Regents of the Smithsonian Institution for the Year Ending June 30, 1927. 12 pp. (Publ. 2924.)

Report of the Acting Secretary of the Smithsonian Institution for the Year Ending June 30, 1927. 131 pp. (Publ. 2923.)

The general appendix to this report, which was in press at the close of the year, contains the following papers:

The Accomplishments of Modern Astronomy, by C. G. Abbot.

Recent Developments of Cosmical Physics, by J. H. Jeans.

The Evolution of Twentieth-Century Physics, by Robert A. Millikan.

Isaac Newton, by Prof. Albert Einstein.

The Nucleus of the Atom, by J. A. Crowther.

The Centenary of Augustin Fresnel, by E. -M. Antoniadi.

Soaring Flight, by Wolfgang Klemperer.

The Coming of the New Coal Age, by Edwin E. Slosson.

Is the Earth Growing Old? By Josef Felix Pompeckj.

Geological Climates, by W. B. Scott.

Geologic Romance of the Finger Lakes, by Prof. Herman F. Fairchild.

Fossil Marine Faunas as Indicators of Climatic Conditions, by Edwin Kirk.

Paleontology and Human Relations, by Stuart Weller.

At the North Pole, by Lincoln Ellsworth.

Bird Banding in America, by Frederick C. Lincoln.

The Distribution of Fresh-water Fishes, by David Starr Jordan.

The Mind of an Insect, by R. E. Snodgrass.

The Evidence Bearing on Man's Evolution, by Aleš Hrdlička.

The Origins of the Chinese Civilization, by Henri Maspero.

Archeology in China, by Liang Chi-Chao.

Indian Villages of Southeast Alaska, by Herbert W. Krieger.

The Interpretation of Aboriginal Mounds by Means of Creek Indian Customs, by John R. Swanton.

Friederich Kurz, Artist-Explorer, by David I. Bushnell, jr.

Note on the Principles and Process of X-Ray Examination of Paintings, by Alan Burroughs.

Lengthening of Human Life in Retrospect and Prospect, by Irving Fisher.

Charles Doolittle Walcott, by George Otis Smith.

William Healey Dall, by C. Hart Merriam.

SPECIAL PUBLICATIONS

Classified List of Smithsonian Publications Available for Distribution, September 15, 1927. Compiled by Helen Munroe. 29 pp. (Publ. 2922.)

List of Paintings, Pastels, Drawings, Prints, and Copper Plates by and attributed to American and European Artists together with a list of Original Whistleriana in the Freer Gallery of Art. March 20, 1928. 51 pp. (Publ. 2963.)

Handbook of the Health Exhibits of the United States National Museum under direction of the Smithsonian Institution. April 6, 1928. 39 pp., 19 figs.

Explorations and Field-work of the Smithsonian Institution in 1927. April 7, 1928. 188 pp., 213 figs. (Publ. 2957.)

REPRINTS

Phonetic Transcription of Indian Languages. Report of American Anthropological Association (Reprint). September, 1916. 15 pp., 2 charts. (Publ. 2415.)

The Origin and Antiquity of the American Indian. By Aleš Hrdlička. From the Smithsonian Report for 1923, pp. 481–494, 16 pls. Revised edition. (Publ. 2778.)

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM

The editorial work of the National Museum is in the hands of Dr. Marcus Benjamin. During the year ending June 30, 1928, the Museum published 1 annual report, 3 volumes of proceedings, 5 complete bulletins, 2 parts of a bulletin, 1 complete volume in the series Contributions from the United States National Herbarium, and 57 separates from the proceedings.

The issues of the bulletin were as follows:

Bulletin 76. Asteroidea of the North Pacific and Adjacent Waters. Part 2. Forcipulata (Part). By Walter Kenrick Fisher.

Bulletin 100. Contributions to the Biology of the Philippine Archipelago and Adjacent Regions. Volume 6, part 4. Report on the Echinoidea collected by the United States Fisheries Steamer "Albatross" during the Philippine Expedition, 1907–1910. Part I. The Cidaridae. By Theodor Mortensen. Volume 7. The Fishes of the Families Pomacentridae, Labridae, and Callyodontidae, collected by the United States Bureau of Fisheries Steamer "Albatross," chiefly in Philippine Seas and Adjacent Waters. By Henry W. Fowler and Barton A. Bean.

Bulletin 141. Collection of Heating and Lighting Utensils in the United States National Museum. By Walter Hough.

Bulletin 142. Life Histories of North American Shore Birds. Order Limicolae (Part 1). By Arthur Cleveland Bent.

Bulletin 143. Biological and Taxonomic Investigations on the Mutillid Wasps. By Clarence E. Mickel.

Bulletin 144. The American Bats of the Genera *Myotis* and *Pizonyx*. By Gerrit S. Miller, jr., and Glover M. Allen.

Of the separates from the proceedings, 12 were from volume 71, 25 from volume 72, and 20 from volume 73.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY

The editorial work has continued under the direction of the editor, Mr. Stanley Searles.

During the year one annual report and one bulletin were issued.

Forty-second Annual Report. Accompanying papers: Social Organization and Social Usages of the Indians of the Creek Confederacy (Swanton); Religious Beliefs and Medical Practices of the Creek Indians (Swanton); Aboriginal Culture of the Southeast (Swanton); Indian Trails of the Southeast (Myer). 900 pp., 17 pls., 108 figs.

Bulletin 85. Contributions to Fox Ethnology (Michelson). 168 pp.

Publications in press are as follows:

Forty-first Annual Report. Accompanying papers: Coiled Basketry in British Columbia and Surrounding Region (Boas, assisted by Haeberlin, Roberts, and Teit); Two Prehistoric Villages in Middle Tennessee (Myer).

Forty-third Annual Report. Accompanying papers: The Osage Tribe: Two Versions of the Child-naming Rite (La Flesche); Wawenock Myth Texts from Maine (Speck); Native Tribes and Dialects of Connecticut (Speck); Picuris Children's Stories, with Texts and Songs (Harrington); Iroquoian Cosmology—Part II (Hewitt).

Forty-fourth Annual Report. Accompanying papers: Excavation of the Burton Mound at Santa Barbara, Calif. (Harrington); Social and Religious Usages of the Chickasaw Indians (Swanton); Uses of Plants by the Chippewa Indians (Densmore); Archeological Investigations II (Fowke).

Bulletin 84. A Vocabulary of the Kiowa Language (Harrington).

Bulletin 86. Chippewa Customs (Densmore).

Bulletin 87. Notes on the Buffalo-Head Dance of the Thunder Gens of the Fox Indians (Michelson).

Bulletin 88. Myths and Tales of the Southeastern Indians (Swanton).

Bulletin 89. Observations on the Thunder Dance of the Bear Gens of the Fox Indians (Michelson).

Bulletin 90. Papago Music (Densmore).

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION

The annual reports of the American Historical Association are transmitted by the association to the secretary of the Smithsonian Institution and are communicated by him to Congress as provided by the act of incorporation of the association.

Part 2 of the annual report for 1922 was issued during the year. The annual reports for 1923, 1924, and 1925 and the supplemental volumes to the reports for 1924, 1925, and 1926 were in press at the close of the year.

REPORT OF THE NATIONAL SOCIETY, DAUGHTERS OF THE AMERICAN REVOLUTION

The manuscript of the Thirtieth Annual Report of the National Society, Daughters of the American Revolution, was transmitted to Congress, in accordance with the law, December 15, 1927.

SMITHSONIAN ADVISORY COMMITTEE ON PRINTING AND PUBLICATION

The editor has continued to serve as secretary of the Smithsonian advisory committee on printing and publication, to which are referred for consideration and recommendation all manuscripts offered to the Institution and its branches. Seven meetings were held during the year and 107 manuscripts acted upon.

Respectfully submitted.

W. P. True, *Editor*.

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 11

LIST OF SUBSCRIBERS TO JAMES SMITHSON MEMORIAL EDITION, SMITHSONIAN SCIENTIFIC SERIES[1]

Mr. J. Henry Alexandre,
New York, N. Y.
Mr. Frederic W. Allen,
New York, N. Y.
Mr. Rayford W. Alley,
New York, N. Y.
Mr. W. J. Anderson,
New York, N. Y.
Mr. Hugh D. Auchincloss,
Washington, D. C.
Mr. Richard B. Ayer,
New York, N. Y.
Mr. Joseph Bancroft,
Wilmington, Del.
Mr. David Bandler,
New York, N. Y.
Mr. George G. Barber,
New York, N. Y.
Mr. J. S. Barnes,
New York, N. Y.
Dr. Grant S. Barnhart,
Washington, D. C.
Mr. William S. Barstow,
New York, N. Y.
Mr. W. H. Barthold,
New York, N. Y.
Mr. Philip G. Bartlett,
New York, N. Y.
Mr. Oliver G. Bauman,
Buffalo, N. Y.
Mr. Barton A. Bean, jr.,
Buffalo, N. Y.
Mr. John P. Bickell,
Toronto, Canada.
Mr. Edwin Binney,
New York, N. Y.
Mr. Charles E. Birge,
New York, N. Y.
Mr. Samuel Shipley Blood,
New York, N. Y.
Mrs. Elizabeth B. Blossom,
Cleveland, Ohio.
Mr. Sidney Blumenthal,
New York, N. Y.
Mr. Samuel T. Bodine,
Philadelphia, Pa.
Mrs. John C. Boyd,
Washington, D. C.
Mr. A. R. M. Boyle,
New York, N. Y.
Mr. Henry Platt Bristol,
New York, N. Y.
Mr. Robert S. Brookings,
Washington, D. C.
Mr. Gerald Brooks,
New York, N. Y.
Mr. Donaldson Brown,
New York, N. Y.
Mr. H. F. Brown,
Wilmington, Del.
Mr. Albert Buchman,
New York, N. Y.
Mr. Britton I. Budd,
Chicago, Ill.

[1] List brought up to date as of Oct. 15, 1928, when manuscript of this report went to the printer.

Mr. Percy Bullard,
New York, N. Y.
Mr. W. Douglas Burden,
New York, N. Y.
Mr. Frederick John Burghard,
New York, N. Y.
Mrs. Stevenson Burke,
Cleveland, Ohio.
Mr. Eric Burkman,
New York, N. Y.
Mr. Smith P. Burton, jr.,
Boston, Mass.
Mr. F. S. Byram,
Philadelphia, Pa.
Mr. William C. Cannon,
New York, N. Y.
Mr. E. A. Cappelan-Smith,
New York, N. Y.
Mr. George W. Carnrick,
New York, N. Y.
Mr. John J. Carty,
New York, N. Y.
Mr. George Cary,
Buffalo, N. Y.
Mr. C. Merrill Chapin, jr.,
New York, N. Y.
Mr. A. Wallace Chauncey,
New York, N. Y.
Mr. George H. Chisholm,
Buffalo, N. Y.
Dr. A. Schuyler Clark,
New York, N. Y.
Mr. Ray Clark,
New York, N. Y.
Mr. John L. Clawson,
Buffalo, N. Y.
Mr. John N. Cole,
New York, N. Y.
Mr. Philip S. Collins,
Philadelphia, Pa.
Mr. Martin Conboy,
New York, N. Y.
Mr. W. L. Conwell,
New York, N. Y.
Prof. Thomas F. Cooke,
Buffalo, N. Y.
Mrs. Q. F. Coonley,
Washington, D. C.
Mr. Dudley Martindale Cooper,
New York, N. Y.
Mr. W. S. Corby,
Washington, D. C.
Mr. Fred D. Corey,
Buffalo, N. Y.
Mr. John W. Cowper,
Buffalo, N. Y.
Mr. William Nelson Cromwell,
New York, N. Y.
Mr. Miquel Cruchaga,
Paris, France.
Mr. E. A. Cudahy, jr.,
Chicago, Ill.
Mr. Victor M. Cutter,
Boston, Mass.
Mr. C. Suydam Cutting,
New York, N. Y.
Señor Don Carlos G. Davila,
Washington, D. C.
Mr. Edgar B. Davis,
New York, N. Y.
Mr. James Sherlock Davis,
Brooklyn, N. Y.
Mr. Frederic A. Delano,
Washington, D. C.
Mr. William Adams Delano,
New York, N. Y.
Mr. Fairman R. Dick,
New York, N. Y.
Mr. Milton S. Dillon,
New York, N. Y.
Mr. L. W. Dommerich,
New York, N. Y.
Mr. Robert Donner,
Buffalo, N. Y.
Mr. Eugene E. du Pont,
Wilmington, Del.
Mr. Henry B. du Pont,
Wilmington, Del.

Mr. Irénée du Pont,
Wilmington, Del.
Mrs. J. Coleman du Pont,
New York, N. Y.
Mr. Lammot du Pont,
Wilmington, Del.
Mr. S. Hallock du Pont,
Wilmington, Del.
Dr. George J. Eckel,
Buffalo, N. Y.
Mr. Louis J. Ehret (2 subscriptions),
New York, N. Y.
Mr. Otto M. Eidlitz,
New York, N. Y.
Mr. Arturo M. Elias,
New York, N. Y.
Mr. George Adams Ellis,
New York, N. Y.
Mr. Duncan Steuart Ellsworth,
New York, N. Y.
Mr. James Radford English,
New York, N. Y.
Mr. William Phelps Eno,
Washington, D. C.
Mr. W. H. Erhart,
New York, N. Y.
Mr. Eberhard Faber,
New York, N. Y.
Mr. Frank J. Fahey,
Boston, Mass.
Mr. James A. Farrell,
New York, N. Y.
Mr. L. F. Fedders,
Buffalo, N. Y.
Mr. Edwin C. Feigenspan,
Newark, N. J.
Mr. Orestes Ferrara,
Washington, D. C.
Mr. W. W. Flowers,
New York, N. Y.
Mr. Stanley D. Fobes,
New York, N. Y.
Mr. Oswald Fowler,
New York, N. Y.
Mr. Richard L. Fox,
Philadelphia, Pa.
Mr. Clayton E. Freeman,
New York, N. Y.
Mr. Herbert G. French,
Cincinnati, Ohio.
Mr. John Hemming Fry,
New York, N. Y.
Mr. Walter D. Fuller,
Philadelphia, Pa.
Judge Arthur G. Gallagher,
New York, N. Y.
Mr. C. P. Gearon,
New York, N. Y.
Mr. Stanley L. Gedney, jr.,
East Orange, N. J.
Mr. Paulino Gerli,
New York, N. Y.
Mr. William P. Gest,
Philadelphia, Pa.
Mrs. John H. Gibbons,
Washington, D. C.
Mr. Michael Gioe, sr.,
New York, N. Y.
Mr. Charles F. Glore,
Chicago, Ill.
Mr. Edward S. Goodwin,
Hartford, Conn.
Mr. Osmer N. Gorton,
New York, N. Y.
Mr. Lyttleton B. P. Gould,
New York, N. Y.
Dr. Louis S. Greene,
Washington, D. C.
Dr. James C. Greenway,
New Haven, Conn.
Mr. John Gribbel,
Philadelphia, Pa.
Mr. George B. Grinnell,
New York, N. Y.

Grosvenor Library,
Buffalo, N. Y.

(Presented by Mr. Ansley Wilcox, Mr. William Schoellkopf, Mr. H. W. Walcott, Mr. Percy G. Lapey, Mr. Edward L. Jellinek, Buffalo, N. Y.)

Mr. Robert L. Hague,
New York, N. Y.
Mr. E. K. Hall,
New York, N. Y.
Mr. William A. Hamann,
New York, N. Y.
Mr. Chauncey J. Hamlin,
Buffalo, N. Y.
Mr. John Hays Hammond,
New York, N. Y.
Dr. Walter S. Harban,
Washington, D. C.
Mr. John R. Hardin,
Newark, N. J.
Mr. Louis A. Harding,
Buffalo, N. Y.
Mr. Franklin Hardinge,
Chicago, Ill.
Mr. Huntington R. Hardwick,
Boston, Mass.
Mr. Anton G. Hardy,
New York, N. Y.
Mr. Fairfax Harrison,
Washington, D. C.
Mr. Philip H. Haselton,
New York, N. Y.
Dr. F. R. Haussling,
Newark, N. J.
Mr. John J. Hearn,
New York, N. Y.
Mrs. A. Barton Hepburn,
New York, N. Y.
Mrs. Sallie A. Hert,
Louisville, Ky.
Mr. Joseph H. Himes,
Washington, D. C.
Mr. Samuel V. Hoffman,
New York, N. Y.
Mrs. Edward Holbrook,
New York, N. Y.
Mr. George E. Holmes,
New York, N. Y.
Mr. Ernest Hopkinson,
New York, N. Y.
Mr. John S. A. Hosford,
New York, N. Y.
Miss Marie O. Hotchkiss,
East River, Conn.
Mr. Allen G. Hoyt,
New York, N. Y.
Mr. Richard F. Hoyt,
New York, N. Y.
Hon. Charles E. Hughes,
New York, N. Y.
Mr. Frederick H. Hurdman,
New York, N. Y.
Mr. William Dunn Hutton,
New York, N. Y.
Mr. A. F. Hyde,
New York, N. Y.
Mr. Charles H. Innes,
Boston, Mass.
Mr. Samuel Insull,
Chicago, Ill.
Mr. Robert F. Irwin, jr.,
Philadelphia, Pa.
Mr. Henry H. Jackson,
New York, N. Y.
Mr. Alfred W. Jenkins,
New York, N. Y.
Mrs. Mary L. Jennings,
Washington, D. C.
Mr. Eldridge R. Johnson,
Camden, N. J.
Mr. James A. Johnson,
Buffalo, N. Y.
Mr. George H. Judd,
Washington, D. C.
Mr. Otto H. Kahn,
New York, N. Y.
Mr. Henry J. Kaltenbach,
New York, N. Y.

Mr. Russell M. Keith,
Cleveland, Ohio.
Dr. Foster Kennedy,
New York, N. Y.
Mr. C. C. Kerr,
New York, N. Y.
Mr. Robert C. Kerr,
New York, N. Y.
Miss Bessie L. Kibbey,
Washington, D. C.
Mr. Gustavus T. Kirby,
New York, N. Y.
Mr. Benjamin Kittinger,
Buffalo, N. Y.
Mr. Seymour H. Knox,
Buffalo, N. Y.
Mr. Edward L. Koons,
Buffalo, N. Y.
Mr. Harry G. Kosch,
New York, N. Y.
Mr. de Lancey Kountze,
New York, N. Y.
Dr. Shepard Krech,
New York, N. Y.
Mr. H. C. Lakin,
New York, N. Y.
Mrs. Marshall Langhorne,
Washington, D. C.
Mr. Irwin B. Laughlin,
Washington, D. C.
Mr. Erich E. Lehsten,
New York, N. Y.
Miss Isobel Lenman (2 subscriptions),
Washington, D. C.
Mr. William Leslie,
New York, N. Y.
Mrs. Frank Letts,
Washington, D. C.
Mr. Henry Lewis,
New York, N. Y.
Mr. Samuel A. Lewisohn,
New York, N. Y.
Mr. Louis K. Liggett,
Boston, Mass.
Mr. James Duane Livingston,
New York, N. Y.
Mr. S. D. Locke,
Bridgeport, Conn.
Mr. Frank Lord,
New York, N. Y.
Dr. Earl P. Lothrop,
Buffalo, N. Y.
Mr. G. R. Lyman,
New York, N. Y.
Mr. Norman E. Mack,
Buffalo, N. Y.
Mr. Clifford D. Mallory,
New York, N. Y.
Mr. Peter J. Maloney, jr.,
New York, N. Y.
Judge Francis X. Mancuso,
New York, N. Y.
Mr. John Markle,
New York, N. Y.
Mr. Richard H. Marshall,
New York, N. Y.
Mr. John C. Martin,
Philadelphia, Pa.
Mr. George Grant Mason,
New York, N. Y.
Mr. B. A. Massee,
Chicago, Ill.
Mrs. Grace H. Mather,
Cleveland, Ohio.
Mr. Cyrus H. McCormick,
Chicago, Ill.
Mr. Henry Forbes McCreery,
New York, N. Y.
Mr. Hubert McDonnell,
New York, N. Y.
Mr. William L. McLean,
Philadelphia, Pa.
Mr. Andrew W. Mellon,
Washington, D. C.
Col. Herman A. Metz,
New York, N. Y.

Mr. John J. Miller,
Washington, D. C.
Mr. Ogden L. Mills,
New York, N. Y.
Mr. John J. Mitchell,
Chicago, Ill.
Mr. Leeds Mitchell,
Chicago, Ill.
Mr. Roscoe R. Mitchell,
Buffalo, N. Y.
Mr. T. E. Mitten,
Philadelphia, Pa.
Mr. Jay R. Monroe,
Orange, N. J.
Mr. Henry E. Montgomery,
Buffalo, N. Y.
Mr. Adelbert Moot,
Buffalo, N. Y.
Mr. J. Pierpont Morgan (2 subscriptions).
New York, N. Y.
Mr. John W. Morgan,
New York, N. Y.
Mr. Frank C. Munson,
New York, N. Y.
Premier Benito Mussolini,
Rome, Italy.
Mr. William E. Nickerson,
Boston, Mass.
Mr. John B. Niven,
New York, N. Y.
Mr. Aaron E. Norman,
New York, N. Y.
Mr. George W. Norris,
Philadelphia, Pa.
Mr. J. J. O'Brien,
Chicago, Ill.
Mr. Lyle H. Olson,
New York, N. Y.
Mr. John Omwake,
Cincinnati, Ohio.
Mr. James L. O'Neill,
New York, N. Y.
Mr. James Parmelee,
Washington, D. C.
Mr. Charles S. Payson,
New York, N. Y.
Mr. Charles Pfeiffer,
New York, N. Y.
Mr. Gustavus A. Pfeiffer,
New York, N. Y.
Mr. Ellis L. Phillips,
New York, N. Y.
Mr. H. M. Pierce,
Wilmington, Del.
Mr. Townsend Pinkney,
New York, N. Y.
Mr. Bayard F. Pope,
New York, N. Y.
Mr. Frederick J. Pope,
New York, N. Y.
Mr. William Cooper Proctor,
Cincinnati, Ohio.
Mr. Ralph Pulitzer,
New York, N. Y.
Mr. Percy R. Pyne, jr.,
New York, N. Y.
Mr. John J. Raskob,
New York, N. Y.
Mr. William F. Raskob,
Wilmington, Del.
Mr. Earle H. Reynolds,
Chicago, Ill.
Mr. Edwin T. Rice,
New York, N. Y.
Mr. E. Ridgeway,
Chicago, Ill.
Mr. Harry G. Rieger,
Philadelphia, Pa.
Mr. Arthur W. Rinke,
New York, N. Y.
Mr. Walter B. Robb,
Buffalo, N. Y.
Mr. William A. Rockefeller,
New York, N. Y.
Mrs. John A. Roebling,
Bernardsville, N. J.

Mr. Saul E. Rogers,
New York, N. Y.
Mr. William H. Rollinson,
New York, N. Y.
Mr. Edward L. Rossiter,
New York, N. Y.
Mr. James Savage,
Buffalo, N. Y.
Mr. Homer E. Sawyer,
New York, N. Y.
Mr. Michael A. Scatuorchio,
Jersey City, N. J.
Mr. H. W. Schaefer,
New York, N. Y.
Mr. William N. Schill,
New York, N. Y.
Mr. L. O. Schmidt,
New York, N. Y.
Mr. Henry Schniewind,
New York, N. Y.
Mr. Alfred H. Schoellkopf,
Buffalo, N. Y.
Mr. J. F. Schoellkopf, jr.,
Buffalo, N. Y.
Mr. Sherman W. Scofield,
Cleveland, Ohio.
Mr. T. A. Scott,
New York, N. Y.
Mr. Jere A. Sexton,
New York, N. Y.
Mr. John C. Shaffer,
Chicago, Ill.
Mrs. Paula W. Siedenburg,
Greenwich, Conn.
Mr. E. H. H. Simmons,
New York, N. Y.
Mrs. Frances G. Simmons,
Greenwich, Conn.
Mr. Z. G. Simmons, jr.,
New York, N. Y.
Mr. Sidney H. Sonn,
New York, N. Y.
Mr. John R. Sproul,
Philadelphia, Pa.
Col. W. C. Spruance,
Wilmington, Del.
Dr. Edward H. Squibb,
Brooklyn, N. Y.
Mr. Andrew Squire,
Cleveland, Ohio.
Dr. A. Camp Stanley,
Washington, D. C.
Mr. Joseph E. Sterrett,
New York, N. Y.
Mr. Aron Steuer,
New York, N. Y.
Mr. John P. Stevens,
New York, N. Y.
Mr. Robert G. Stone,
Boston, Mass.
Mr. James J. Storrow, jr.,
Boston, Mass.
Mr. D. H. Strachan,
New York, N. Y.
Mr. Charles L. Sturtevant,
Washington, D. C.
Mr. Gerard P. Tameling,
New York, N. Y.
Mr. Arthur Van Rensselaer Thompson,
New York, N. Y.
Mr. George W. Thompson,
New York, N. Y.
Mr. John R. Thompson, jr.,
Chicago, Ill.
Mr. Ralph E. Thompson,
Boston, Mass.
Mr. J. C. Thorn,
New York, N. Y.
Mr. Francis B. Thorne,
New York, N. Y.
Dr. Edward C. Tillman,
New York, N. Y.
Mr. John H. Towne,
New York, N. Y.
Mr. J. Barton Townsend,
Philadelphia, Pa.

Dr. Raynham Townshend,
New Haven, Conn.
Mr. J. C. Trees,
Pittsburgh, Pa.
Gen. Harry C. Trexler,
Allentown, Pa.
Mr. George F. Trommer,
Brooklyn, N. Y.
Mr. Calvin Truesdale,
New York, N. Y.
Mr. George Tyson,
Boston, Mass.
Mr. Ernest Uehlinger,
New York, N. Y.
Mr. Alvin Untermyer,
New York, N. Y.
Mr. George P. Urban,
Buffalo, N. Y.
Mr. George Urquhart,
New York, N. Y.
Mr. Ray A. Van Clief,
Buffalo, N. Y.
Mr. William H. Vanderbilt,
New York, N. Y.
Mrs. S. H. Vandergrift,
Washington, D. C.
Mr. S. M. Vauclain,
Philadelphia, Pa.
Mr. George E. Waesche,
New York, N. Y.
Mr. Sidney S. Walcott,
Buffalo, N. Y.
Mr. Thomas John Watson,
New York, N. Y.
Mr. F. O. Wetmore,
Chicago, Ill.
Mr. F. Edson White,
Chicago, Ill.
Col. Frank White,
Chattanooga, Tenn.
Mr. Lazarus White,
New York, N. Y.
Mr. Thomas W. White,
New York, N. Y.
Mr. Philip J. Wickser,
Buffalo, N. Y.
Mr. Milo W. Wilder, jr.,
Newark, N. J.
Mr. Howard L. Wilkins,
Washington, D. C.
Mr. Charles B. Williams,
New York, N. Y.
Mr. William H. Williams,
New York, N. Y.
Mr. Joseph Wilshire,
New York, N. Y.
Mr. William E. Winchester,
New York, N. Y.
Mr. C. Chalmers Wood,
New York, N. Y.
Mr. Howard O. Wood, jr.,
New York, N. Y.
Mr. Charles H. Woodhull,
Washington, D. C.
Mr. George C. Woolf,
New York, N. Y.
Mr. Clarence M. Woolley,
New York, N. Y.
Mr. Beverly Lyon Worden,
New York, N. Y.
Mr. Max Wulfsohn,
New York, N. Y.
Mr. Frederic L. Yeager,
New York, N. Y.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDED JUNE 30, 1928

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds, receipts, and disbursements of the Institution and a statement of the appropriations by Congress for the following Government bureaus in the administrative charge of the Smithsonian Institution: The National Museum, the International Exchanges, the Bureau of American Ethnology, the National Zoological Park, the Astrophysical Observatory, the International Catalogue of Scientific Literature, and the National Gallery of Art; also for an additional assistant secretary and for printing and binding for the fiscal year ended June 30, 1928.

SMITHSONIAN INSTITUTION

Condition of the endowment fund June 30, 1928

The sum of $1,000,000, deposited in the Treasury of the United States under act of Congress, is part of a permanent endowment fund, which includes the original Smithson fund and additions accumulated by the deposit of savings and bequests from time to time. Subsequent bequests and gifts and the income therefrom, when so required, are invested in approved securities. The several specific funds so invested are now constituted and classed as follows:

Consolidated fund

Avery fund	$44, 244. 60
Bacon, Virginia Purdy, fund	62, 272. 93
Baird, Lucy H., fund	1, 783. 88
Canfield, collection fund	46, 232. 86
Casey, Thomas L., fund	1, 000. 00
Chamberlain fund	35, 000. 00
Endowment fund	41, 542. 80
Hachenberg fund	5, 000.00
Hamilton fund	500. 00
Henry, Caroline, fund	1, 425. 45
Hodgkins, general fund	37, 275. 00
Hughes, Bruce, fund	16, 108. 72
Myer, Catherine Walden, fund	18, 649. 43

Pell, Cornelia Livingston, fund	$3,000.00
Poore, Lucy T., and George W., fund	24,847.89
Reid, Addison T., fund	9,810.48
Rhees fund	523.38
Roebling fund	150,000.00
Sanford, George H., fund	955.18
Smithson fund	1,516.40
Stock dividends not yet credited to various funds	1,280.00
Total consolidated fund	502,969.00
Springer, Frank, fund	30,000.00
Walcott, Charles D., and Mary Vaux, research fund	11,520.00
Younger, Helen Walcott, fund (held in trust)	49,812.50

The total amount of dividends, interest, etc., received by the Institution from the Freer bequest during the year for all purposes was $286,705.06, and the amount received from sale, call, etc., of Freer bequest stocks, bonds, etc., was $580,486.07.

The itemized report of the auditor, the Capital Audit Co., certified public accountants, is filed in the office of the secretary.

CLASSIFIED RECEIPTS AND EXPENDITURES

Parent fund

Balance June 30, 1927		$15,324.93
Receipts, consisting of interest and receipts from miscellaneous sources, available for general purposes	$57,985.02	
International exchanges, repayments to the Institution	5,151.12	
Total receipts		63,136.14
Total resources for general purposes		78,461.07
General expenditures:		
Care and repair of buildings	7,525.90	
Furniture and fixtures	601.00	
General administration	24,532.65	
Library	3,710.30	
Publications (comprising preparation, printing, and distribution)	17,173.12	
Researches and exploration	3,563.00	
International exchanges	6,557.18	
Total general expenditures		63,663.15
Balance June 30, 1928		14,797.92

Funds for specific objects, including payment and return of funds advanced for field expenses and other temporary transactions during the year

Balance June 30, 1927		$87,097.38
Receipts:		
Abbott, archeological exploration in Dominican Republic fund	$785.30	
Abbott, Haitian and Santo Domingan expedition fund	941.60	
Abbott, China expedition fund	265.02	
Avery fund	3,226.07	

Receipts—Continued.

Bacon, Virginia Purdy, fund	$3,358.32	
Baird, Lucy H., fund	96.15	
Beach African expedition fund	219.11	
Canfield collection fund	46,846.79	
Casey, Laura Welsh, fund	256.88	
Casey, Thomas L., fund	2,053.93	
Chamberlain, Frances Lea, fund	1,887.55	
Dall bibliography and library funds	3,700.00	
Daly, Marcus, fund	500.00	
Edison rubber collecting expedition fund	2,453.09	
Endowment fund	41,527.55	
Frick vertebrate paleontological exploration fund	548.43	
Hachenberg fund	269.65	
Hamilton fund	176.96	
Harriman Trust fund	12,700.00	
Harvard University botanical expedition to Honduras fund	600.00	
Henry, Caroline, fund	76.85	
Hodgkins fund, specific	7,195.07	
Hughes, Bruce, fund	868.70	
Loeb, Morris, fund	1,479.56	
Myer, Catherine Walden, fund	1,286.89	
New York Commission on Ventilation, Radiation from Human Body fund	1,006.00	
North American Wild Flowers publication fund	41,683.64	
Osage fund	500.00	
Pell, Cornelia Livingston, fund	2,673.73	
Poore, Lucy T. and George W., fund	2,940.19	
Reid, Addison T., fund	1,189.05	
Research Corporation fund for researches in solar radiation	15,067.50	
Rhees fund	63.60	
Roebling fund	8,144.63	
Sanford, George H., fund	117.50	
Simpson, Charles T., fund	1,976.50	
Smithsonian-Chrysler expedition fund	370.93	
Smithsonian Scientific Series fund	2,002.42	
Springer, Frank, fund	2,250.00	
Swales fund	317.10	
Walcott, Charles D. and Mary Vaux, fund	1,239.19	
Younger, Helen Walcott, fund	18,296.17	
Refund of temporary advances, etc	11,771.81	
Total receipts		$244,929.43
Cash capital from sale, call, etc., of securities (to be reinvested)		58,350.50
Total resources		390,377.31

Expenditures:

Abbott, archeological exploration in Dominican Republic fund, expended	$750.00	
Abbott, China expedition fund, expended	750.00	
Avery fund, invested	3,788.14	
Bacon, Virginia Purdy, fund, expended	3,278.78	

Expenditures—Continued.

Baird, Lucy H., fund, invested	$55.79	
Beach African expedition fund, expended	219.11	
Canfield collection fund, invested	46,232.86	
Casey, Laura Welsh, fund, expended	886.88	
Casey, Thomas L., fund, invested	1,000.00	
Chamberlain, Frances Lea, fund, expended	3,693.22	
Cottrell, Frederick G., fund, expended	500.00	
Edison rubber collecting expedition fund, expended	2,453.09	
Endowment fund, invested	40,547.55	
Endowment fund, campaign, expended	32,630.63	
Frick vertebrate paleontological exploration fund, expended	500.00	
Hamilton fund, expended	408.00	
Harriman Trust fund, expended	10,340.72	
Harvard University botanical expedition to Honduras fund, expended	600.00	
Henry, Caroline, fund, invested	202.12	
Hodgkins fund, specific, expended	7,741.45	
Hughes, Bruce, fund, invested	1,949.82	
Loeb, Morris, fund, expended	2,977.43	
Myer, Catherine Walden, fund, invested	4,031.43	
New York Commission on Ventilation, Radiation from Human Body fund, expended	390.28	
North American Wild Flowers publication fund, expended	42,068.42	
Osage fund, expended	700.00	
Pell, Cornelia Livingston, fund, invested and expended	3,471.51	
Poore, Lucy T. and George W., fund, invested and expended	3,613.47	
Reid, Addison T., fund, invested	2,511.32	
Research Corporation fund for researches in solar radiation, expended	7,500.00	
Rhees fund, invested	166.04	
Roebling fund, expended	4,053.66	
Roebling, John A., solar research, etc., fund, expended	9,779.36	
Sanford, George H., fund, invested	279.46	
Simpson, Charles T., fund, expended	138.05	
Smithsonian-Chrysler expedition fund, expended	2,200.00	
Springer, Frank, fund, expended	1,696.60	
Swales fund, expended	193.12	
Walcott, Charles D. and Mary Vaux, fund, expended	2,025.65	
Younger, Helen Walcott, fund, invested and expended	18,078.67	
Temporary advances for field expenses, etc	19,284.24	
Total expenditures	283,686.87	
Reinvestment of cash capital received from sale, call, etc., of securities	59,157.75	
Total		$342,844.62
Balance June 30, 1928		47,532.69

Charles L. Freer bequest

Balance on hand June 30, 1927		$100, 405. 18
Receipts:		
Dividends, interest, and miscellaneous receipts	$286, 705. 06	
Sale and call of stocks, bonds, etc. (gain)	61, 069. 72	
Cash capital from sale, call, etc., of stocks, bonds, etc. (to be reinvested)	519, 416. 35	
Total receipts		867, 191. 13
Total resources		967, 596. 31
Expenditures:		
Operating expenses of gallery, salaries, purchase of art objects, field expenses, and incidentals	152, 412. 99	
Investment of funds	89, 058. 50	
Reinvestment of cash capital	550, 086. 02	
Total expenditures		791, 557. 51
Balance June 30, 1928		176, 038. 80

SUMMARY

Total balances of all funds June 30, 1927		202, 827. 49
Receipts of year ending June 30, 1928:		
Parent fund, for general purposes	63, 136. 14	
Revenue and principal of funds for specific objects except Freer bequest	244, 929. 43	
Cash capital, for reinvestment, except Freer bequest	58, 350. 50	
Freer bequest, dividends, interest, etc	286, 705. 06	
Freer bequest, sale, call, etc., stocks and bonds (capital gains)	61, 069. 72	
Freer bequest, cash capital for reinvestment	519, 416. 35	
Total receipts		1, 233, 607. 20
Total resources		1, 436, 434. 69
Expenditures:		
Parent fund, for general purposes of the Institution	63, 663. 15	
Specific objects, except Freer bequest	283, 686. 87	
Cash capital, reinvested	59, 157. 75	
Freer bequest, operating expenses, etc	152, 412. 99	
Freer bequest, invested	89, 058. 50	
Freer bequest, cash capital reinvested	550, 086. 02	
Total expenditures		1, 198, 065. 28
Total balances of all funds June 30, 1928		238, 369. 41
Total		1, 436, 434. 69

BALANCE SHEET OF THE INSTITUTION, JUNE 30, 1928

ASSETS

Stocks and bonds at acquirement value:		
Consolidated fund	$502, 969. 00	
Freer bequest	4, 268, 244. 26	
Springer fund	30, 000. 00	
Walcott fund	11, 520. 00	
Younger fund	49, 812. 50	
		$4, 862, 545. 76
United States Treasury deposit		1, 000, 000. 00
Miscellaneous—principally funds advanced for printing publications and field expenses (to be repaid)		35, 990. 97
Cash:		
Funds in United States Treasury and in banks	$237, 969. 41	
On hand, for petty transactions	400. 00	
		238, 369. 41
		6, 136, 906. 14

LIABILITIES

Freer bequest—capital accounts:		
Court and grounds fund	394, 574. 09	
Court and grounds maintenance fund	81, 586. 40	
Curator fund	330, 022. 46	
Residuary estate fund	3, 462, 061. 31	
		4, 268, 244. 26
Consolidated fund—capital accounts		503, 157. 00
Springer fund—capital		30, 000. 00
Walcott fund—capital		11, 520. 00
Younger fund—capital		49, 812. 50
United States Treasury deposit—capital		1, 000, 000. 00
Freer bequest—current accounts:		
Court and grounds fund	25, 074. 56	
Court and grounds maintenance fund	4, 240. 16	
Curator fund	10, 965. 97	
Residuary estate fund	124, 341. 77	
Stocks and bonds, sales, etc	11, 416. 34	
		176, 038. 80
Springer fund—current account		1, 293. 40
Walcott fund—current account		645. 00
Younger fund—current account		217. 50
Miscellaneous cash accounts held by the Institution, for the most part for specific use		95, 977. 68
		6, 136, 906. 14

All payments are made by check, signed by the Secretary of the Institution, on the Treasurer of the United States, and all revenues are deposited to the credit of the same account. In some instances deposits are placed in bank for convenience of collection and later are withdrawn in round amounts and deposited in the Treasury.

The practice of investing temporarily idle funds in time deposits has proven satisfactory. During the year the interest derived from this source, together with other similar items, has resulted in a total of $5,215.32.

CAPITAL AUDIT COMPANY, *October 31, 1928.*

EXECUTIVE COMMITTEE, BOARD OF REGENTS,
Smithsonian Institution,
Washington, D. C.

SIRS: We have examined the accounts and vouchers of the Smithsonian Institution for the fiscal year ended June 30, 1928, and certify the balance of cash on hand June 30, 1928, to be $238,369.41.

The vouchers representing payments from the Smithsonian income during the year, each of which bears the approval of the secretary or, in his absence, of the acting secretary, and a certificate that the materials and services charged were applied to the purposes of the Institution, have been examined in connection with the books of the Institution and agree with them.

Respectfully submitted.

CAPITAL AUDIT COMPANY,
WILLIAM L. YAEGER,
Certified Public Accountant.

The following appropriations for the Government bureaus in administrative charge of the Smithsonian Institution were made by Congress for the fiscal year 1928:

Bureau:		Appropriation
International Exchanges		$46,855
American Ethnology		58,720
International Catalogue of Scientific Literature		7,260
Astrophysical Observatory		32,060
Additional Assistant Secretary		7,500
National Museum:		
Furniture and fixtures	$26,500	
Heating and lighting	79,500	
Preservation of collections	473,510	
Building repairs	13,000	
Books	1,500	
Postage	450	
Gallery	12,500	
		606,960
National Gallery of Art		30,356
National Zoological Park		175,000
National Zoological Park—building for birds		25,000
Printing and binding		90,000
Total		1,079,711

Respectfully submitted.

FREDERIC A. DELANO,
R. WALTON MOORE,
JOHN C. MERRIAM,
Executive Committee.

PROCEEDINGS OF BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE FISCAL YEAR ENDED JUNE 30, 1928

ANNUAL MEETING DECEMBER 8, 1927

Present: Chief Justice William H. Taft, chancellor, in the chair; Senator Reed Smoot, Senator Woodbridge N. Ferris, Senator Joseph T. Robinson, Representative Albert Johnson, Representative R. Walton Moore, Representative Walter H. Newton, Mr. Frederic A. Delano, and the acting secretary, Dr. Charles G. Abbot.

Dr. Alexander Wetmore, assistant secretary, was also present.

The first business was the presentation of the Langley medal to Col. Charles A. Lindbergh. The presentation was made on behalf of the board by Chief Justice William H. Taft, chancellor, and in accepting the medal Colonel Lindbergh expressed his appreciation and stated that the *Spirit of St. Louis* would later be offered to the Institution for permanent exhibition. A full account of the presentation is given in the annual report of the secretary.

The acting secretary announced the death of Mr. Henry White, and Mr. Johnson submitted the following resolutions, which were adopted:

Whereas the Board of Regents of the Smithsonian Institution, having learned of the death on July 15, 1927, of the Hon. Henry White, a member of the board for over 10 years, and latterly the chairman of its executive committee: Therefore be it

Resolved, That the board here record an expression of their very sincere regret at the passing away of their colleague, whose demise is at once a heavy loss to the Institution and a personal sorrow to the members of the board. Mr. White's distinguished career as a diplomat, which is too well known to be recited here, well fitted him for his duties as a Regent, and his ripened judgment and keen interest in the affairs of the Institution will be greatly missed.

Resolved, That a copy of this resolution be transmitted by the acting secretary to the family of Mr. White.

The acting secretary then announced the death of Mr. Charles F. Choate, jr., and stated that on behalf of the Board of Regents he had attended the funeral services at Southboro, Mass.

The chancellor spoke briefly of the high esteem in which Mr. Choate was held by the bar, and of the great clearness and fine finish of his arguments before the court. Mr. Moore also made eulogistic

remarks, after which Mr. Newton offered the following resolutions, which were adopted:

Whereas the Board of Regents of the Smithsonian Institution having learned of the death, on November 30, 1927, of Charles Francis Choate, jr., a distinguished leader of the Boston bar for many years, and a Regent of this Institution since February 24, 1908: Therefore be it

Resolved, That the board desire here to record an expression of their profound sorrow at the passing away of a friend whose splendid qualities endeared him to his associates on the board, and of a colleague who was ever ready to devote his best efforts in advancing the interests and prestige of the Smithsonian Institution, whose past was to him a source of pride and in whose future he had unbounded faith.

Resolved, That a copy of these resolutions be transmitted by the acting secretary to the family of Mr. Choate.

Mr. Delano submitted the following customary resolution, which was adopted:

Resolved, That the income of the Institution for the fiscal year ending June 30, 1929, be appropriated for the service of the Institution, to be expended by the secretary, with the advice of the executive committee, with full discretion on the part of the secretary as to items.

Regarding the bequest to the Institution of the late Secretary Walcott the following resolutions were adopted:

Whereas the Board of Regents of the Smithsonian Institution having been informed of the bequest to the Institution by its late secretary, Charles D. Walcott, of $50,000, subject to a life interest of his daughter, Helen B. Walcott (now Helen Walcott Younger), said bequest on her decease to be transferred in its entirety to the Charles D. and Mary Vaux Walcott research fund and become a part thereof, and be treated in the same manner as the original donation to that fund; and

Whereas it is also provided by the said testator that if at any time before or after the death of said daughter, Helen Walcott Younger, the Smithsonian Institution shall have been placed under the control of any executive department or branch of the Federal Government, the said bequest of $50,000, both principal and any interest that may have accrued at the time of such transfer, shall then be paid to the George Washington University, of Washington, D. C.: Therefore be it

Resolved, That the board hereby unqualifiedly accepts the said bequest, together with all the conditions imposed therein, with an expression of its grateful appreciation of the late secretary's generosity.

The acting secretary submitted the annual report of the executive committee showing the financial condition of the Institution for the fiscal year ending June 30, 1927, which, on motion, was received.

The annual report of the National Gallery of Art Commission was presented, and, on motion, the following resolution was adopted:

Resolved, That the Board of Regents hereby approves the recommendation of the National Gallery of Art Commission that James E. Fraser, J. H. Gest, F. J. Mather, jr., and E. C. Tarbell be reelected as members of the commission for the ensuing term of four years, their present terms having expired.

The acting secretary then presented a special report on a number of important matters, including the endowment movement, the Smith-

sonian Scientific Series, the North American Wild Flowers series, the Freer bequest, the Industrial Museum, the National Historical Maritime Museum, the proposed National Gallery of Art building, and the Hachenberg bequest. On motion it was

Resolved, That the special report of the acting secretary, together with the recommendations made by him, be referred to the permanent committee for later consideration.

The special committee on the future policy of the Institution appointed at a previous meeting of the board presented its report, and, after discussion, several resolutions were adopted, among them one to elect Mr. Delano as chairman of the executive committee, and another increasing the membership of the permanent committee to six, to consist of the executive committee, the secretary, and two other members of the board, and naming Senators Smoot and Robinson as the two new members.

SPECIAL MEETING JANUARY 10, 1928

Present: Chief Justice William H. Taft, chancellor, in the chair; Vice President Charles G. Dawes; Senator Reed Smoot; Senator Woodbridge N. Ferris; Senator Joseph T. Robinson; Representative Albert Johnson; Representative R. Walton Moore; Representative Walter H. Newton; Hon. Irwin B. Laughlin; Mr. Frederic A. Delano; Dr. John C. Merriam; and the acting secretary, Dr. Charles G. Abbot.

Dr. Alexander Wetmore, assistant secretary, was also present.

The acting secretary announced that under date of December 12, 1927, the Speaker had reappointed Representatives Albert Johnson, R. Walton Moore, and Walter H. Newton as Regents of the Institution.

He also stated that the President had signed joint resolutions appointing the following as citizen Regents for six years from the dates given:

December 21, 1927: The Hon. Charles Evans Hughes, of New York.

December 21, 1927: Dr. John C. Merriam, of Washington, D. C.

After remarks by the acting secretary, outlining in general terms the history and purposes of the Research Corporation, he introduced Dr. F. G. Cottrell, who made the original gift which resulted in the organization of the corporation. Doctor Cottrell made a statement regarding the affairs of the corporation, and, after remarks by the Regents, Mr. Moore introduced the following resolution, which was adopted:

Resolved, That the permanent committee is requested to consider with the board of directors of the Research Corporation what further arrangements, if any, should be made with reference to the matter discussed at this meeting by Dr. F. G. Cottrell and report at the next meeting of the Board of Regents.

Mr. Delano stated that a vacancy existed in the membership of the executive committee and offered the following resolution, which was adopted:

Resolved, That Dr. John C. Merriam be elected a member of the executive committee of the Board of Regents of the Smithsonian Institution.

Mr. Delano, chairman, reported on a number of important things which have been under consideration by the executive and permanent committees.

On motion, the report was received.

At this point Doctor Abbot and Doctor Wetmore withdrew from the meeting.

Mr. Delano then presented a report recommending to the Board of Regents for election to the position of secretary the name of Dr. Charles G. Abbot, at present the acting secretary, and offered the following resolution, which was unanimously adopted:

Resolved, That the vacancy in the position of secretary of the Smithsonian Institution be filled by the election of Dr. Charles Greeley Abbot.

Doctor Abbot was then recalled to the meeting and notified of his election. He expressed his appreciation of the high honor conferred upon him, and his assurance that his very best efforts would be put forth to further increase the usefulness and prestige of the Institution.

Senator Robinson here said that he would like the opportunity to express the board's congratulations to Doctor Abbot and its confidence that he would carry on the great work of the Institution with success.

POSTPONED MEETING FEBRUARY 17, 1928

Present: Hon. Charles G. Dawes, Vice President of the United States, in the chair; Senator Reed Smoot, Senator Woodbridge N. Ferris, Senator Joseph T. Robinson, Representative Albert Johnson, Representative Walter H. Newton, Mr. Frederic A. Delano, Hon. Irwin B. Laughlin, Dr. John C. Merriam, and the secretary, Dr. Charles G. Abbot.

Dr. Alexander Wetmore, assistant secretary, was also present.

The secretary reported that as directed by the Board of Regents, a meeting in memory of Doctor Walcott was held at the National Museum on January 24, 1928. The meeting, which was well attended, was presided over by the Chancellor of the Institution, and addresses on the late secretary's life and work were made by Dr. John C. Merriam, president of the Carnegie Institution of Washington; Dr. Joseph S. Ames, chairman of the National Advisory Committee for Aeronautics; Dr. George Otis Smith, Director of the United States Geological Survey; and by the secretary, representing the Smithsonian Institution and the National Academy of Sciences. An ac-

count of the meeting, together with the addresses made, will be printed in due time.

The secretary presented to the board several subjects of interest that had come up since the last meeting, among them the matter of a gift to the endowment of the Institution by Mr. Dwight W. Morrow, a Regent, and the following resolution was adopted:

Resolved, That the board express their thanks to their colleague not only for his generosity in making this large contribution but even more for his invaluable counsel and service in promoting the welfare of the Institution, and direct the secretary to communicate this resolution to him.

Mr. Delano, as chairman of the permanent committee, reported upon the status of several important administrative matters.

The secretary submitted to the board in writing a statement of his policy for the future activities of the Institution.

SPECIAL MEETING MARCH 15, 1928

Present: Chief Justice William H. Taft, chancellor, in the chair; Vice President Charles G. Dawes; Senator Reed Smoot; Senator Joseph T. Robinson; Representative Albert Johnson; Representative Walter H. Newton; Mr. Irwin B. Laughlin; Mr. Charles E. Hughes; and the secretary, Dr. Charles G. Abbot.

Dr. Alexander Wetmore, assistant secretary, and Admiral David W. Taylor, United States Navy, were present by invitation.

After a discussion of the so-called "Langley-Wright controversy," the following resolution was adopted:

Whereas to correct any erroneous impression derived from published statements that the Smithsonian Institution has denied to the Wright brothers due credit for making the first successful human flight in power-propelled, heavier-than-air craft:

Resolved, That it is the sense of the Board of Regents of the Smithsonian Institution that to the Wrights belongs the credit of making the first successful flight with a power-propelled heavier-than-air machine carrying a man.

SPECIAL MEETING APRIL 5, 1928

Present: Chief Justice William H. Taft, chancellor, in the chair; Vice President Charles G. Dawes; Senator Claude A. Swanson; Representative R. Walton Moore; Mr. Frederic A. Delano; Mr. Irwin B. Laughlin; Mr. Charles E. Hughes; Dr. John C. Merriam; and the secretary, Dr. Charles G. Abbot.

Dr. Alexander Wetmore, assistant secretary, was also present.

The secretary announced the death of Senator Woodbridge N. Ferris, a Regent.

After remarks, Mr. Moore offered the following resolution, which was adopted:

Whereas the Board of Regents of the Smithsonian Institution have learned of the death, on March 23, 1928, of the Hon. Woodbridge N. Ferris, United

States Senator from Michigan, and a Regent of the Institution for the past three years: Therefore be it

Resolved, That the board desire to record here their profound sorrow at the loss sustained by the passing away of this distinguished scholar and statesman and their colleague, whose deep interest in the Institution made him a valued member of this board.

Resolved, That this resolution be conveyed by the secretary to the family of Senator Ferris, with an expression of the board's sincere sympathy in this hour of their bereavement.

The secretary stated that on March 28, 1928, the Vice President of the United States had appointed the Hon. Claude A. Swanson, Senator from Virginia, as a Regent to succeed Senator Ferris.

The secretary reminded the board that at the meeting of February 17, 1928, a resolution had been adopted appointing Messrs. Hughes, Robinson, and Moore as a committee to consider the provisions in the Freer gift and bequest that have been the subject of various interpretations, and to report to the board. The secretary had accordingly supplied the members of the committee with the papers in the case, and the committee was now functioning, under the chairmanship of Mr. Hughes.

The secretary recalled to the board that at the meeting of February 17 last it was stated that the Research Corporation had indicated that it might be able to place $15,000 at the Institution's disposal this year to promote fundamental researches in radiation. He was pleased to announce that a check for this amount had been received and duly acknowledged.

The Vice President congratulated the secretary upon this result, as well as upon his election to the board of directors of the Research Corporation.

On motion of Mr. Moore, the secretary was requested to convey in suitable terms the thanks of the board for this grant to the Institution.

In compliance with the request of the board, the secretary submitted a detailed statement of the financial needs of the Institution.

The Vice President here said that at the meeting of February 17 the permanent committee had submitted a report containing a recommendation in regard to the campaign for the endowment fund of the Institution. This item of the report was again brought before the board for consideration and, after discussion, the following resolution was adopted:

Resolved, That the matter of increasing the unrestricted endowment fund be placed in the charge of Mr. Frederic A. Delano, with power to appoint the members of a committee who shall aid him in perfecting and executing plans for this purpose.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1928

ADVERTISEMENT

The object of the GENERAL APPENDIX to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions, reports of investigations made by collaborators of the Institution, and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution from a very early date to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and, during the greater part of its history, this purpose has been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880, induced in part by the discontinuance of an annual summary of progress which for 30 years previously had been issued by well-known private publishing firms, the secretary had a series of abstracts prepared by competent collaborators, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1928.

THE WIDER ASPECTS OF COSMOGONY [1]

By J. H. Jeans, Sec. R. S.

[With three plates]

Interest in scientific cosmogony is a recent and still a very tender growth. Anthropologists and geologists tell us that man has existed on earth for something like 300,000 years; we must go this far back to meet our apelike ancestry. Between them and us some 10,000 generations of men have walked the earth, most of whom have probably given some thought, in varying degree, to the significance of their existence and the plan of the universe.

Of these 10,000 generations of men, the first 9,990 unhesitatingly regarded the earth as the center, and terrestrial life as the central fact, of the universe. As was suited to its majesty and dignity as the abode of man, the earth stood still while the celestial sphere spun around it, covering in the earth much as a telescope dome covers in the telescope; and this dome was spangled with stars, which had been thoughtfully added so as not to leave the central earth unillumined at night. Ten generations at most have been able to view the problem of their existence in anything like its proper astronomical perspective.

THE POSITION OF MAN IN THE UNIVERSE

The total age of the earth far exceeds the 300,000 years or so of man's existence. The evidence of geology, and of radioactivity in rocks in particular, shows that it must be something like 2,000 million years, which is several thousand times the age of the human race. Old Mother Earth must regard man as a very recent apparition indeed; he has just appeared to burrow into her, burn her forests, put her waterfalls into pipes, and generally mar the beauty of her features. If he has done so much in the first few moments of his existence, she may well wonder what is in store for her in the long future ages in which he is destined to labor on her surface.

[1] The Trueman Wood lecture delivered before the Royal Society of Arts on Wednesday, Mar. 7, 1928. Reprinted by permission from Supplement to Nature, No. 3047, Mar. 24, 1928.

For in all probability the life in front of the human race must enormously exceed the short life behind it. A million million years hence, so far as we can foresee, the sun will probably still be much as now, and the earth will be revolving round it much as now. The year will be a little longer, and the climate quite a lot colder, while the rich accumulated stores of coal, oil, and forest will have long been burned up; but there is no reason why our desendants should not still people the earth. Perhaps it may be unable to support so large a population as now, and perhaps fewer will desire to live on it. On the other hand, mankind, being three million times as old as now, may—if the conjecture does not distress our pessimists too much—be three million times as wise.

Looked at on the astronomical time scale, humanity is at the very beginning of its existence—a newborn babe, with all the unexplored potentialities of babyhood; and until the last few moments its interest has been centered, absolutely and exclusively, on its cradle and feeding bottle. It has just become conscious of the vast world existing outside itself and its cradle; it is learning to focus its eyes on distant objects, and its awakening brain is beginning to wonder, in a vague, dreamy way, what they are and what purpose they serve. Its interest in this external world is not much developed yet, so that the main part of its faculties is still engrossed with the cradle and feeding bottle, but a little corner of its brain is beginning to wonder.

Taking a very gloomy view of the future of the human race, let us suppose that it can only expect to survive for 2,000 million years longer, a period about equal to the past age of the earth. Then, regarded as a being destined to live for threescore years and ten, humanity, although it has been born in a house 70 years old, is itself only 3 days old. But only in the last few minutes has it become conscious that the whole world does not center round its cradle and its trappings, and only in the last few ticks of the clock has any adequate conception of the size of the external world dawned upon it.

For our clock does not tick seconds, but years; its minutes are the lives of men. A minute and a half ago the distance of a star was first measured and provided a measuring rod for the universe. A quarter of a minute ago, Hertzsprung and Shapley showed how the peculiar stars known as Cepheid variables provide a longer measuring rod, and taught us to think in distances so great that light takes hundreds of thousands of years to traverse them. With the very last tick of the clock, Hubble, using the same measuring rod, has found that the most remote objects visible in the biggest telescope on earth are so distant that light, traveling 186,000 miles a second, takes about 140 million years to come from them to us.

Not only is our vision of the universe continually expanding, but also it is expanding at an ever-increasing rate. Is this expansion des-

tined to go on forever? So far as we can at present see, no; for a general guiding principle, that of generalized relativity, fixes a limit, which we are fast approaching. According to this theory, space can not extend forever; it has no limit, but is nevertheless finite like the surface of the earth. Without exploring and surveying the whole of the earth's surface, we can make a fair estimate of its total area by measuring its radius, which we can do by measuring its curvature at any one point. In the same way the total volume of space is fixed by a quantity, the curvature of space, which can be determined by measuring the density of distribution of matter in space. Space which contained no matter would go on forever, but the parts of space we can survey with our telescopes contain enough matter to show that we already see an appreciable fraction of the whole of space. It is as though our baby, watching ships coming from over the horizon, concluded that the earth's surface was curved and formed a general rough conception of its size by imagining the observed curvature continuing until the earth's surface rounded back on itself.

Exact figures are impossible, but Hubble has calculated that space is not likely to extend to more than about a thousand times as far as the farthest nebula visible in the biggest telescope. Nothing prevents our going on and on in space beyond this distance, but if we do we merely come back to ourselves. The possessor of a sufficiently sensitive wireless apparatus may emit signals and pick them up a seventh of a second later after they have traveled round the world. In the same way a not inconceivable increase in the size of our telescopes would take us around the whole of space, and we should see the stars surrounding our sun by light which had traveled round the universe, not of course as they now are, but as they were 100,000 million years ago.

Such considerations make it improbable that the expansion of the universe can continue at its present rate for much longer. Having grasped that the world is round, the infant speedily forms a fair idea of its size. Our particular infant, mankind, has made the great discovery of the existence of the outer world, has formed some conception of its size, and adjusted his ideas, not by a process of slow revelation, but by a brain flash of the last few seconds. In his mature years and his staid old age he is no doubt destined to make many sensational discoveries, but he can never again live through the immortal moment at which he first grasped the immensity of the outer world. We only live through a few ticks of his clock, and fate might have ordained that they should be anywhere in the three days that the child has already lived, or in the 70 long, and possibly tedious years yet to come. The wonderful thing is that she has

selected for us what is, perhaps, in some ways the most sensational moment of all in the life of our race.

The child sets its newly awakened mind to work to adjust and coordinate a new array of facts. If the world was not made to surround its cradle, what purpose can it serve? If the lights of the great ships in the harbor were not designed to light its nursery at night, what can they possibly be for? And, most interesting problem of all, if the world is such a big affair, can there be other cradles and other babies?

These remarks will have served their purpose if they suggest that what I am rashly trying to set forth here should not be judged as a finished science or the solution of a problem; it is rather the first confused gropings of the infant mind trying to understand the world outside its cradle. And if the impression produced by its first inexperienced glance at the outer world had to be described in a single word, it would probably select the word "immensity."

THE IMMENSITY OF SPACE

The immensity of space is measured by the figures already mentioned. Light and wireless signals travel at the same rate because, of course, they are essentially the same thing; and this thing takes a seventh of a second to travel round the world, and probably something like 100,000 million years to travel round the universe. The ratio of these times (2×10^{19}) measures the dimensions of the universe in terms of the familiar dimensions of the world; incidentally, it also measures the expansion of our spatial ideas since Copernicus. The disparity of size is too great to be easily visualized. Suppose the size of our earth were represented by a single atom. Then the range of vision of the biggest telescope is about represented by the whole earth, and the size of the whole universe, according to the theory of relativity, is represented by a stack of 1,000 million earths.

Scarcely less bewildering than the immense extent of space is the immense amount and variety of matter it contains. The sun, which is a million times as big as the earth and three hundred thousand times as massive, proves to be something less than a grain of sand on the seashore. It forms one of a family whose number must certainly be counted in thousands of millions; Seares has estimated it at 30,000 millions. This is not the only family of stars in space. Each of the great spiral and other extragalactic nebulæ, such as are shown in Plates 1, 2, and 3, is either a family of stars, or consists of stars in the making, or of matter which is destined ultimately to form stars. We can estimate the masses of these great nebulæ by gravitational means, and each is found to contain enough matter to make 1,000 million suns. This of itself will give some conception of the vast

size of these nebulæ, but to tell the whole story, it must be added that their colossal masses are so tenuous that each millionth part of an ounce is, on the average, as big as the Matterhorn. Think of a body which is bigger than the Matterhorn by as much as 1,000 million suns is heavier than a millionth part of an ounce, and we have the size of any one of these great nebulæ. Any one of the three photographs here reproduced would have to be enlarged so as to cover the whole of Asia before a body of the size of the earth became visible in it at all, even under the most powerful of microscopes.

Hubble estimates that about 2,000,000 such nebulæ are visible in the great 100-inch telescope at Mount Wilson, and that the whole universe has about a thousand million times the volume of that part of space visible in this telescope. Let us now multiply 1,000 million by 2 million, and the product by 1,000 million. The answer (2×10^{24}) gives some indication of the probable number of stars in the universe; the same number of grains of sand spread over England would make a layer hundreds of yards in depth. Let us reflect that our earth is one millionth part of one such grain of sand, and our mundane affairs, our troubles and our achievements, begin to appear in their correct proportion to the universe as a whole.

While the stars may fairly be compared to grains of sand in number, they differ too much inter se for the comparison to be carried further. There is an enormous variety of big and little stars, of bright and faint stars, of red and blue stars, and of hot, hotter, and still hotter stars. The faintest of known stars (Wolf 359) emits only a fifty thousandth part of the light of the sun, while the brightest (S. Doradus) emits three hundred thousand times as much light as the sun. The smallest known star (Van Maanen's star) is about the size of the earth; a million such stars could be packed inside the sun and leave room to spare. The largest known star (Betelgeuse) is so large that 25 million suns could be packed inside it. Their ranges are greater than those between a searchlight and a glowworm, or between balloons and birdshot.

Yet the stars are essentially similar structures. A normal atom consists of a central nucleus round which a number of electrons revolve like planets round the sun—a miniature solar system, in fact, in which the vacant space far exceeds that occupied by matter. With great heat the electrons begin to break loose and fly off at a tangent. The central temperatures of the stars can be calculated with fair precision, and prove to be so high that most of the electrons must have already broken loose from their atoms. Of recent years, a great deal of labor has been devoted to testing the hypothesis that practically all the electrons have so broken loose, the stripped atoms and electrons flying about in a general hurly-burly like the molecules

of a gas. But the hypothesis has proved disappointing, and a much more probable hypothesis is, I think, that the atoms are not stripped quite bare, but that in most stars they retain a few rings of electrons which give the atoms so much size that they jostle one another about like the molecules of a liquid. This hypothesis explains beautifully the otherwise puzzling fact that stars of large mass fall into distinct groups of what may almost be described as "standardized" sizes. On the "liquid-star" hypothesis, these different sizes correspond to the different sizes possible for the stellar atoms which may have 0, 1, 2, or 3 rings of electrons left, but can not have fractional numbers. The largest stars of all, such as Betelgeuse, have three rings left, while minute stars, such as Van Maanen's star, consist of atoms most of which are stripped quite bare, so that there is almost no limit to the closeness with which they can be packed together. An average handful of the matter of which this star is composed would contain about 10 tons.

Thus the observed sizes of the stars proclaim the secret of the structure of the atom. The sizes of the stars are discontinuous because the sizes of atoms broken down to different stages are discontinuous. These discontinuities can be traced in turn to the discontinuities which form the central feature of the new quantum dynamics. Thus the distinguishing characteristic of the laws which govern the most minute processes in nature is transmitted directly into the large-scale phenomena of astronomy and governs the distribution of the huge masses of the stars. The infinitely great is never very far from the infinitely small in science, but it would be hard to find a more sensational illustration of the unity of science than that I have just given.

On this hypothesis, not only do the observed sizes of the stars disclose the general structure of the atom, which is old knowledge, but they also reveal the detailed structure of the particular atoms of which the stars are composed, and this is new knowledge. To be precise, the observed sizes of the stars disclose the atomic weights of the stellar atoms; they indicate that the stellar atoms are probably rather heavier than the heaviest atom, uranium, known on earth. The atoms which reveal their presence in stellar spectra are, of course, atoms of the ordinary terrestrial elements—hydrogen, iron, calcium, and the like. These, being the lightest atoms in the star, must naturally float up to its surface, and as the earth was originally formed out of the surface of the sun the earth is necessarily composed of them. But it now appears likely that down in the depths of the stars are other unknown and heavier atoms. We may almost say that it must be so, for no terrestrial atoms, not even radium or uranium, can produce anything like the amount of energy which these stellar atoms are observed to produce.

THE IMMENSITY OF TIME

The immensity of space is paralleled by that of time. We can estimate the ages of stars from the impression that time has made upon them, just as we estimate the age of a tree from the number of subdivisions of its stem, or of rings in its cross section. There are three principal methods of doing this. The orbits of binary stars, which are circular at birth, are gradually knocked out of shape by the forces from passing stars. As we can calculate the rate at which this process occurs, the shape of stars' orbits can be made to reveal their ages. The moving clusters provide a second method. Groups of bright stars such as the Great Bear, the Pleiades, Orion's Belt, are often found to consist of exceptionally massive stars which move in regular orderly formation through a jumble of slighter stars, like a flight of swans through a confused crowd of rooks and starlings. Swans, however, are conscious beings and continually adjust their flight so as to preserve their formation. The swanlike stars can not do this, so that their orderly formation must in time be broken by the gravitational pull of other stars. When this happens, the lighter stars are naturally knocked out of formation first, while the most massive stars retain their formation longest. This agrees with what is observed, and as we can calculate the time necessary to knock out the lighter stars, we can at once deduce the ages of those which are left in. A third method of investigation rests upon a rather abstruse dynamical theorem, which shows that after a sufficient time the energies of motion of the different types of stars must tend to equality, the little stars making up for the smallness of their mass by the rapidity of their motion. Seares has shown that the stars near the sun have nearly attained to this ideal state, and as we can calculate the time needed to establish it we can again deduce the ages of the stars.

It is gratifying and significant that all three lines of investigation lead to the same result: The stars are found to be some millions of millions of years old, perhaps from 5 to 10 millions of millions. We can not state their age with much precision, but it is the general order of magnitude, not the exact figure, that is important.

STELLAR RADIATION

Year after year, century after century, for millions of millions of years, the sun radiates enough energy from each square inch of its surface to keep a 50-horsepower engine continually in action; still hotter stars may radiate as much as 30,000 horsepower per square inch. If this energy were produced by the combustion of coal, the stars would all be completely burnt out in a few hundreds or thou-

sands of years. Where, then, shall he find a source of energy to last millions of millions of years?

More than 20 years ago I directed attention to the enormous store of energy made available by the annihilation of matter, by positive and negative electrons falling into and annihilating one another, thus setting free the whole of their intrinsic energy as radiation. On this scheme neither energy nor matter had a permanent existence, but only a sort of sum of the two; each was, theoretically at least, convertible into the other. Whether energy is ever transformed into matter we do not know; probably not. But the falling together of electrons and protons forms the obvious mechanism for the transformation of matter into energy, and it now seems practically certain that this is the actual source of the radiation of the stars. A beam of radiation exerts pressure on any surface it falls upon, just as a jet of water does or a blast of air. The reason is that radiation carries mass about with it, and electromagnetic theory tells us the amount of this mass. For example, we can calculate that a searchlight which is radiating 50 horsepower of energy is discharging mass into space with the radiation at the rate of a gram and quarter a century; with sufficiently delicate adjustments it might even be possible to observe the recoil of the searchlight. Indeed, the pressure of radiation has actually been measured although not in this particular way. New mass is of course being continually fed into the searchlight by the electric current.

Each square inch of the sun's surface is in effect a searchlight discharging radiation into space at the rate of 50 horsepower, and so is discharging mass at the rate of a gram and a quarter a century, and the sun's surface is so large that the sun as a whole is discharging mass into space at the rate of 250 million tons a minute. Now the sun has no source of replenishment. It must have weighed 360,000 million tons more yesterday than to-day, and by to-morrow will weigh 360,000 million tons less. These are not mere speculative statements; they rest on observation, and on generally accepted principles which are directly confirmed by observation.

Allowing for the fact that a more massive star emits more radiation than a less massive one, we can calculate that 5 or 10 million million years ago the sun must have been several times as massive as it is to-day, so that it has already lost most of the mass it had at birth. Of each ton it had at birth only a few hundredweights at most remain to-day. The loss of mass which accompanies radiation is, then, no mere academic hairsplitting. It is a real astronomical phenomenon, and young stars must be many times as massive as old stars.

There is a certain amount of direct evidence of this change of mass. The radiation of the stars imposes an endlessly recurring capital levy upon their masses, which, as observation shows, is graduated and increases very steeply indeed for the richest stars. The levy makes all the stars poorer, but it also tends to equalize what wealth remains; the older the stars get, the more nearly equal their impoverished masses become. This is a large part of the reason why the stars are nearly equal in mass. The process is most clearly marked in the binary systems, which have been formed by a single star breaking into two. The two component stars of such a system are necessarily of the same age, and it is a matter of observation that the small stars of old systems are nearer to equality of mass than the massive stars of young systems.

Thus observation and theory agree in indicating that the universe is melting away into radiation. Our position is that of polar bears on an iceberg that has broken loose from the ice pack surrounding the pole, and is inexorably melting away as the iceberg drifts to warmer latitudes and ultimate extinction.

Five million million years ago the sun had stored up within itself the energy which was destined to provide its light and heat until to-day, and the mass of this energy was many times the present mass of the sun. No means is known by which so much mass could be stored except in the form of electrons and protons. Thus we must suppose that the radiation of the sun through these millions of millions of years has been produced by the annihilation of electrons and protons which existed in it originally, but no longer exist now. These electrons and protons are pure bottled energy; the continuous breakage of these bottles in the sun sets free the radiation which warms and lights our earth, and enough unbroken bottles remain to provide light and heat for millions of millions of years to come.

The amount of energy made available in this way is amazing. The annihilation of a pound of coal a week would produce as much energy as the combustion of the 5,000,000 tons a week which are mined in the British Isles; an ounce of coal a month would provide locomotive power for all the British railways, while a single drop of oil would take the *Mauretania* across the Atlantic. When we speak of the efficiency of a steam engine as 5 per cent or so, we regard complete use of the thermal energy of combustion as 100 per cent efficiency. If we measure the work done against the total intrinsic energy of the fuel as made available by its complete annihilation, the efficiency is more like 0.00000001 per cent. On this scale the efficiency of the sun and stars is exactly 100 per cent.

Modern physical theory shows that the annihilation of an electron must produce a single flash of radiation of wave length far shorter than any we can produce on earth. As this radiation threads its way through a star its wave length is continually increased, or to use the technical term the radiation is continually softened. In time it becomes γ radiation, then hard X radiation, then soft X radiation, and finally it emerges from the surface of the star as ordinary light and heat. Consider, however, an electron which is annihilated, not inside a star but outside in free space, or in one of the almost transparent nebulæ. The short wave-length radiation now undergoes no softening, but travels on until it meets something capable of checking it. Thus all astronomical bodies, including the surface of the earth, ought to be under continual bombardment by radiation of shorter wave length, and consequently of greater penetrating powers, than any we can produce on earth.

Many years ago such radiation was detected in the earth's atmosphere by McLennan, Rutherford, and other observers; it has recently been studied in detail by Millikan and others. There is no reason to doubt that it originates just where it ought to, namely, in the great nebulæ, and its amount is about what it ought to be if it is evidence of the whole universe melting away into radiation. The wave length of the radiation might be expected to reveal the physical process by which it is generated, but the evidence is a bit puzzling. The hardest terrestrial radiation penetrates inches of lead and corresponds to a voltage of hundreds of thousands of volts. The cosmic radiation penetrates about 5 yards of lead, and the hardest rays are now found to correspond to about 60,000,000 volts.[1] Millikan was at one time inclined to attribute the rays to the combination of 4 atoms of hydrogen to form an atom of helium, but rays so produced would only be of the hardness corresponding to 30,000,000 volts. There are many ways known to physics of softening radiation, but none of hardening it. Thus we must look for some source more energetic than the synthesis of hydrogen into helium, and I can see no possible stopping place short of the annihilation of matter. Again, we are not dealing with a minute phenomenon of mere academic interest. In a sense this radiation is the most fundamental physical phenomenon of the whole universe, most regions of space containing more of it than of visible light or heat. Our bodies are traversed by it night and day. Short of going down into a mine or in a submarine we can not escape it, and it is so intense that it breaks up several million atoms in each of our bodies every second. It may be essential to life or it may be killing us.

---

[1] Added in proof: The recent complete theory of Klein and Nishina gives about 940,000,000 volts, which is precisely the voltage to be expected if the rays originate in the annihilation of matter.—J. H. J.

THE LIVES OF THE STARS

The stars are almost certainly born in nebulæ of the type of the great extragalactic nebulæ, such as are shown in Plates 1, 2, and 3. These nebulæ show a great variety of shapes, but a single thread connects them all; they are the shapes of huge masses of gas endowed with different amounts of rotation. So definitely is this the case that when Hubble recently tried to classify the shapes of these nebulæ, deliberately and avowedly shutting his eyes to all theoretical considerations, he found that purely observational considerations compelled him to classify them in precisely the sequence I had predicted on theoretical grounds some 10 years earlier.

A huge mass of gas which was entirely devoid of rotation would, of course, assume a strictly spherical shape; rotation would flatten this shape out, just as the earth is flattened by its rotation, until ultimately most of the matter was spread out in a thin disk. We see the process beginning in Plate 1, and it is well advanced in Plate 2. Plate 3 shows a nebula which is probably physically similar to that shown in Plate 2, but viewed from another angle. Now, mathematical theory shows that the thin disklike structure could not remain a mere featureless mass of gas. Just as the cooling of a cloud of steam causes it to condense into drops of water, so the cooling of a cloud of gas causes it to condense into detached masses. We see the phenomenon in progress in nebular photographs; it is a necessary theoretical consequence of the laws of gases and the law of gravitation.

Now, the same theory which predicts that the phenomenon must happen predicts the scale on which it will happen. We can calculate how much matter will go to the formation of each "drop," and the calculated masses of the drops come out to be just about the same as the masses of the stars. Indeed, these drops are stars, and the process just described is that of the birth of stars. Unmistakable stars have been observed in the outer regions of many of the spiral nebulæ. It is naturally not possible to identify every observed spot of light with a star, but some of them show precisely the same peculiar fluctuations of light as characterize a certain class of variable star, the Cepheid variables already mentioned, and these put the identity of these particular spots of light beyond all reasonable doubt.

In these nebulæ, then, we are watching the birth of stars, the transformation of an inchoate mass of gas into an "island universe" of stars. Indeed Hubble found it necessary to end up his classification of nebulæ with clouds of stars. At one end of his continuous sequence is a nebula shaped like a mass of rotating gas, in which not a single star is visible; at the other end a star cloud in which nothing

but stars are visible. Our galactic system of stars is probably the final product of just such a transformation, the Milky Way still recording the position of the equatorial plane of the original nebula.

Stars born in this way may meet with a variety of accidents, and these result in different observed astronomical formations. A star may rotate too fast for safety, just as a flywheel may; when this happens it breaks into two, and the two stars so formed revolve endlessly about one another as a binary system. Two stars may run into one another, although this is very rare. A more common occurrence is for two stars to escape running into one another by a narrow shave. When this happens, huge tides are raised on the two stars involved, and these may take the form of long streamers of gas, which ultimately condense into "drops" just as did the gas in the outlying regions of the spiral nebulæ. It seems reasonably certain that the planets were formed in this way.

The birth of the solar system, then, resulted from the close approach of two stars; if a second star had not happened to come close to our sun, there would have been no solar system. It may be thought that with a life of millions of millions of years behind it, one star or another would have been certain to come near enough at some time to tear planets out of the body of our sun. Calculation shows the reverse; even after their long lives of millions of millions of years, only about 1 star in 100,000 can be surrounded by planets born in this way. A quite unusual accident is necessary to produce planets, and our sun with its family of attendant planets is rather of the nature of an astronomical freak.

In the 1,000 million stars surrounding our sun there are, at a moderate computation, not more than 10,000 planetary systems, because there has not been time for more than this number to be born. They are of course still coming into existence; calculation suggests a birth-rate of about 1 per 1,000 million years. Thus we should have to visit thousands of millions of stars before finding a planetary system of as recent creation as our own, and we should have to visit millions of millions of stars before finding a planet on which civilization and interest in the outer universe were as recent a growth as are our own. We are standing at the first flush of the dawn of civilization and are terribly inexperienced beings.

It may be suggested that the creation of planetary systems is also only beginning, and that in time every star will be surrounded, like our sun, by a family of planets. But no; the stars will have dissolved into radiation or disappeared into darkness before there is time for this to happen. So far as we can judge, our part of the universe has lived the more eventful part of its life already; what we are witnessing is less the rising of the curtain before the play than the burning

out of candle ends on an empty stage on which the drama is already over. There is not time for many more planets to be born.

LIFE AND THE UNIVERSE

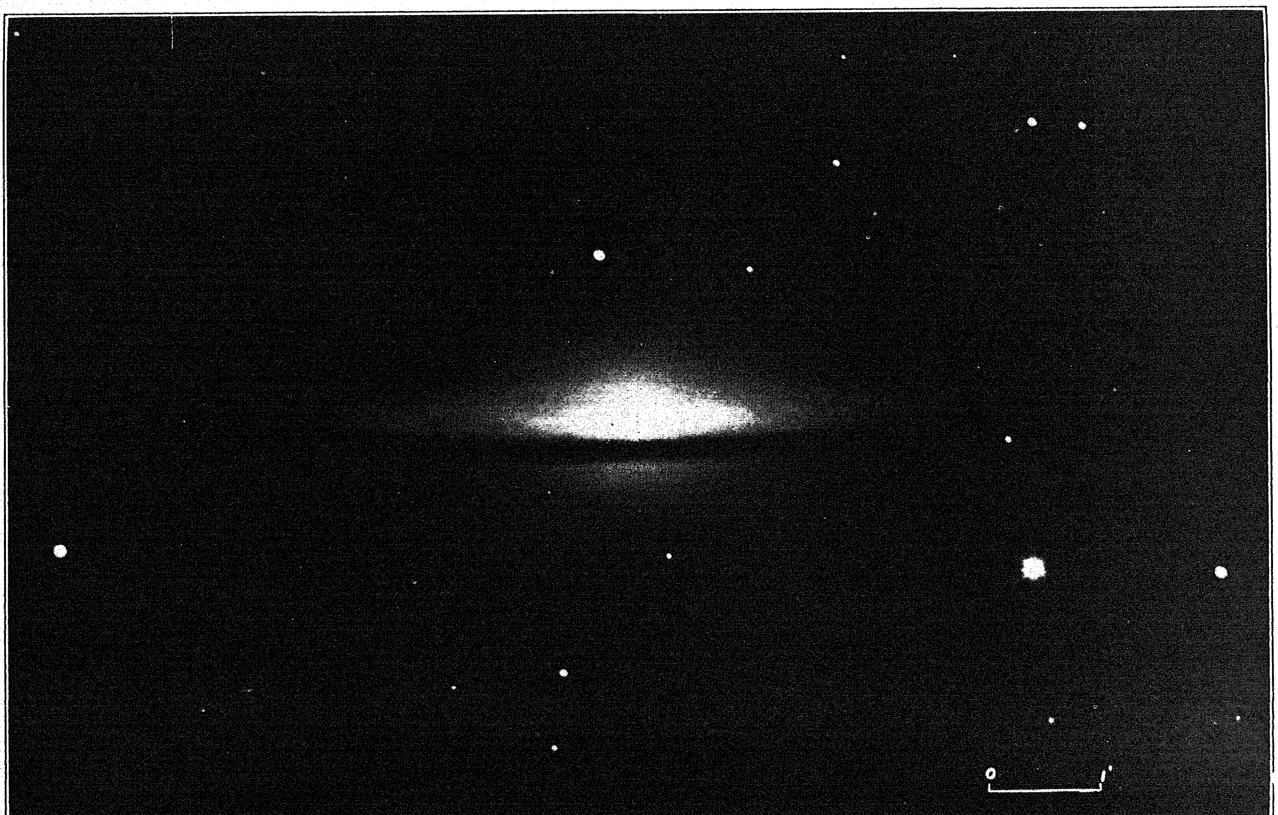
The planets are the only places we know where life can exist. The stars are too hot; even their atoms are broken up by the intense heat. Nebulæ are in every way unsuitable; even if cool solid bodies exist in them, they would probably be so drenched with highly penetrating radiation as to render life impossible. Life demands a special type of matter, such as does not produce intense light and heat by transforming itself into radiation. We find it only in the surfaces of the stars, which are too hot for life, and in the planets which have been pulled out of these surfaces.

On any scheme of cosmogony, life must be limited to an exceedingly small corner of the universe. To our baby's wonderings whether other cradles and other babies exist, the answer appears to be that there can at best be very few cradles, and there is no conceivable means of knowing whether they are tenanted by babies or not. We look out and see a universe consisting primarily of matter which is transforming itself into radiation, and producing so much heat, light, and highly penetrating radiation as to make life impossible. In rare instances special accidents may produce bodies such as our earth, formed of a special cool ash which no longer produces radiation, and here life may be possible. But it does not at present look as though nature had designed the universe primarily for life; the normal star and the normal nebula have nothing to do with life except making it impossible. Life is the end of a chain of by-products; it seems to be the accident, and torrential deluges of life-destroying radiation the essential.

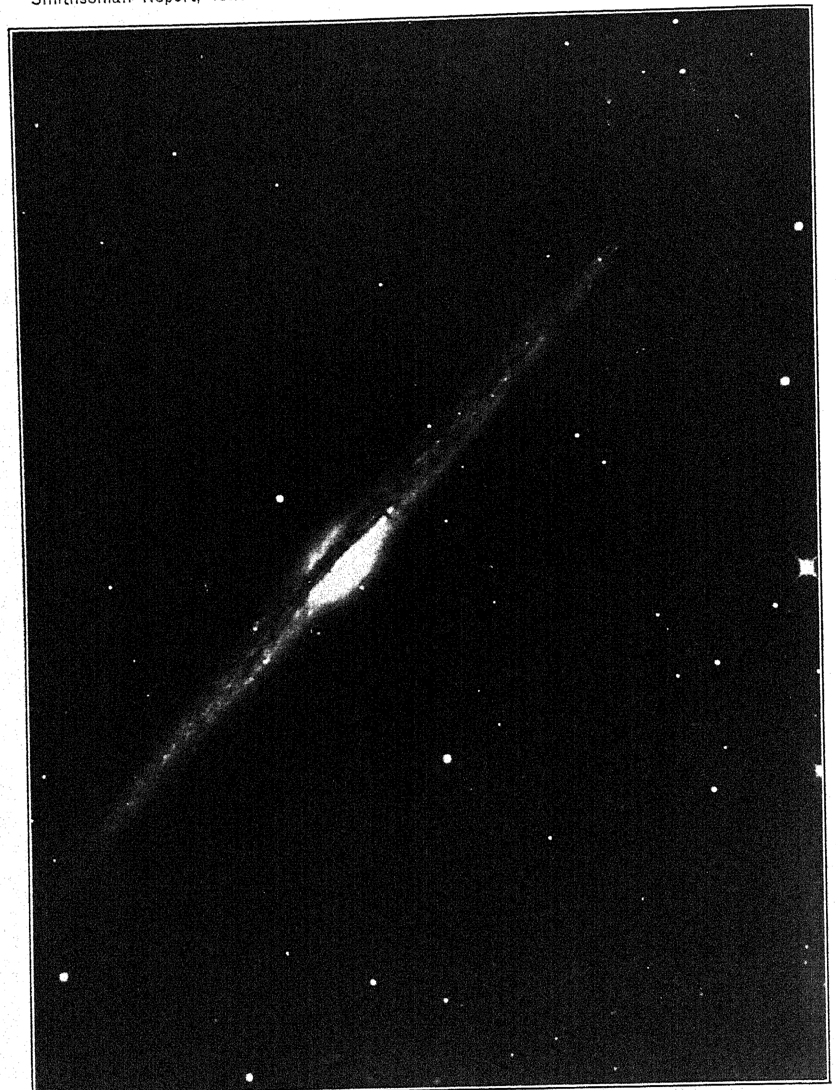
There is a temptation to base wide-reaching inferences on the fact that the universe as a whole is apparently antagonistic to life. Other quite different inferences might be based on the fact of our earth being singularly well adapted to life. We shall, I think, do well to avoid both. Each oak in a forest produces many thousands of acorns, of which only one succeeds in germinating and becoming an oak. The successful acorn, contemplating myriads of acorns lying crushed, rotten, or dead on the ground, might argue that the forest must be inimical to the growth of oaks, or might reason that nothing but the intervention of a special providence could account for its own success in the face of so many failures. We must beware of both types of hasty inference.

In any case our 3-days-old infant can not be very confident of any interpretation it puts on a universe which it only discovered a

minute or two ago. We have said it has 70 years of life before it, but in truth its expectation of life would seem to be nearer to 70,000 years. It may be puzzled, distressed, and often irritated at the apparent meaninglessness and incomprehensibility of the world to which it has suddenly wakened up. But it is still very young; it might travel half the world over before finding another baby as young and inexperienced as itself. It has before it time enough and to spare in which it may understand everything. Sooner or later the pieces of the puzzle must begin to fit together, although it may reasonably be doubted whether the whole picture can ever be comprehensible to one small, and apparently quite insignificant, part of the picture. And ever the old question obtrudes itself as to whether the infant has any means of knowing that it is not dreaming all the time. The picture it sees may be merely a creation of its own mind in which nothing really exists except itself; the universe which we study with such care may be a dream, and we brain cells in the mind of the dreamer.



REGULAR SHAPED NEBULA (N. G. C. 4594) WITH RING OF DARK MATTER SURROUNDING EQUATOR



SPIRAL NEBULA IN COMA BERENICES (N. G. C. 4565) SEEN EDGE ON

SPIRAL NEBULA IN URSA MAJOR (M. 81)

THE STARS IN ACTION[1]

By Alfred H. Joy

This is an age of action. Progress and change are the order of the day. Illustrated papers which can be read at a glance, motion pictures for entertainment and instruction, and the ever-increasing speed of locomotion by motor cars and airplanes indicate the popular tendency. Public interest and attention are rapidly diverted from one activity to another. The ever-changing array of passing heroes is the result of a common desire for novel activity in many lines of effort. No matter how fine the museum exhibit of the results of art or industry, the crowds of young and old turn away to surround the display with a mechanical adaptation which shows some actual process at work.

Among the stars the lover of astronomy finds a fascinating story of activity which claims his supreme interest. The heavenly bodies reveal to the present-day scientist the irresistible charm of action in many different aspects, from the tremendous bustle of atoms and electrons to the stately movement of giant orbs three hundred times the diameter of our sun.

Probably the recognition of life, especially intelligent life, on the moon or one of the planets would be the astronomical discovery that would evoke the greatest popular interest. In 1835 the New York Sun printed an account of life on the moon which purported to come from the observations of Sir John Herschel with a new mammoth telescope 24 feet in aperture located at the Cape of Good Hope in South Africa. It was a most clever hoax, depicting forms of life on the moon far different from those existing on the earth. Trees, animals, and flying men were described in detail, and their habits of life as observed were skillfully pictured. These stories were continued in installments on several successive days. The office of the Sun was stormed for copies and back numbers. New York was almost frantic. All other topics of conversation were forgotten. In a few days the Sun, which had been established only two years,

[1] A popular lecture given Dec. 15, 1927, under the auspices of the Astronomical Society of the Pacific at Culbertson Hall, California Institute of Technology, Pasadena, Calif. Reprinted by permission from the Publications of the Astronomical Society of the Pacific, Vol. XL, April, 1928.

had the largest circulation of any newspaper in the world at that time.

In recent years, on account of the failure to find any signs of life, the study of the moon has been rather neglected by the large observatories. For many years Mars has held the limelight of public interest because of the possibility of life there. Recent observations point to daytime temperatures favorable to life, but the nights are excessively cold. Very meager amounts of atmosphere and water vapor have been observed. In the sun and stars, all of which have immensely high surface temperatures extending from 2,000° to 25,000° C., there is, of course, no possibility of life, for there all chemical compounds, with few exceptions, are dissociated. In the interiors even the atoms are broken up. The astronomer must confess that he can not point with certainty to any form of life except on our tiny earth. Nevertheless, much of interest is found in the physical activity of the stars.

The earliest astronomical discoveries were connected with the bodies of the solar system and their movements, real or apparent. After noting the daily rising and setting of the sun and stars and the monthly changes of the moon's phases and positions, as well as occasional eclipses and comets, probably the first facts of astronomy to be observed were the motions of the planets and the yearly motion of the sun among the stars. Previous to the invention of the telescope some attention was given to the position and brightness of stars, but they were considered to be fixed in position and with few exceptions constant in brightness.

With the invention of the astronomical telescope by the immortal Galileo, intense interest, such as has never been felt at any other time in the history of science, was awakened in astronomy. The theoretical researches of Kepler and Copernicus appealed to a few scientists and philosophers, but actually to see with the eye the Milky Way and star clusters resolved, the spots moving across the face of the sun, the satellites revolving around the planet Jupiter, and to note the changing position of the rings of Saturn were facts of such engrossing interest and concern to everyone that the prevailing authority of the church and science were alike shaken to their foundations because at that time they had no room for new facts in their established dogmas.

The desire to know more of the stars led observers to make increasingly accurate records of the positions and the brightness of the stars, which resulted in the discovery that the stars are not at all fixed in position but have individual motions and that some of them even vary in brightness. These simple observations some 200 years ago were the beginnings of modern observational astronomy. The motions of the stars furnish data for studying the universe as a

whole, while the discovery of variation of brightness was the first step in the study of the stars as individual entities.

The total motion of a star may be resolved into two components, one toward or away from the observer in the line of sight, called radial velocity, and the other at right angles to it, known as proper motion. Radial velocity of stars was thought indeterminable 60 years ago, but the use of the spectroscope—that beautiful optical appliance which, by analyzing light and spreading it out into its various wave lengths and colors, has meant so much to astronomy and physics in the last 50 years—has made it possible to measure the velocities of the stars in the line of sight. Distance does not matter, provided only the star is bright enough to record its light rays on the photographic plate. The largest telescope can photograph the spectra of stars as faint as the tenth or eleventh magnitude and determine their velocities from single plates.

Proper motion can be observed by noting the positions of stars as compared with their positions observed 10, 50, or 100 years before. The largest proper motion known is that of Barnard's star, a faint star of the tenth magnitude, which moves among its neighbors at the rate of 10 seconds of arc a year. This motion would carry it across a space equal to the moon's apparent diameter in 180 years. Although it seems slow, yet such is the extreme accuracy of modern photographic methods that the motion could be detected on plates separated by a time interval of only 24 hours. On account of their great distances most stars have proper motions which are comparatively insignificant, as far as short periods of time are concerned. The nearer stars have, on the average, the greater proper motion because they mark out greater angular distances in the sky as they move.

With proper motion and line-of-sight velocity known, we can calculate the total motion in space of those stars whose distance can be determined. Space motions are the foundations of the study of the structure and dynamical behavior of our universe. They give a clue to the origin and relationships of stars which can be found in no other way. For the nearer stars, at least, it appears that there is a tendency to move through space in groups at certain speeds and in certain directions. Many such groups, composed of a few hundreds or thousands of stars, are known among our nearer neighbors. Smaller groups composed of three or four stars, or even two stars, are numerous. These have the same motion in space and revolve about each other in orbits, as the moon revolves about the earth. They can usually be resolved by the telescope and can be observed as they leisurely describe their orbits in periods varying from a few years to many centuries. A number of the

24034—29——13

binary stars are so close together that they appear single as seen from the earth, even with the most powerful telescopes, and their duplicity is known only by the fact that their orbital motions in the line of sight are shown by the spectroscope. Many of these spectroscopic binaries have periods less than a day, and the two stars of the pair are so close together that they almost touch each other. Our Milky Way system, comprising billions of stars, is made up of such smaller groups, while it, in turn, seems to be a larger unit, a cluster or perhaps a spiral nebula, with a definite motion as a whole.

Another activity of the stars which has had an increasing importance in astronomy since it was first discovered is the variation of total luminosity as seen from the earth. This enticing field of observation has been so attractive to all interested in the heavens that hundreds of amateurs all over the world are devoting their time and talents to the observation of stellar light changes. The thrill of seeing one of the lucid stars of the sky periodically dimming or enhancing its brightness is an experience never to be forgotten. The study of stellar variation has been not only a hobby or useful diversion for the amateur, but has commanded the efforts of nearly all the greatest astronomers of the last hundred years. The brighter stars have been observed with the naked eye; the fainter ones have required the most powerful instruments that could be had. Much time is being given to these objects at the largest observatories. About one-third of the time of the 100-inch telescope is now being devoted to variable stars of different kinds.

The first scientific record of variation among the stars seems to be that concerning the appearance of Tycho Brahe's new star, or nova, in 1572. This was a very bright nova, appearing in Cassiopeia at a point where no star had been known before. It was as bright as Venus at its brightest and could be seen in the daytime. After a few months it disappeared from view, as there were no telescopes at that time to follow it further. On account of the lack of accurate observations of its position, it can not certainly be located at the present time, but it is probably identical with a faint star of the fourteenth magnitude. It has therefore decreased in brightness at least 17 magnitudes, or six million times, since its historic and record-breaking outburst.

Some 50 novæ or temporary stars have appeared since that time. The number has increased with the use of better instruments and with the aid of photography. Many recall Nova Aquilæ which was discovered on June 8, 1918, as a first-magnitude star. Photographs show that for 30 years previous it was an unknown and inconspicuous eleventh-magnitude star in the Milky Way. Some time about June 6 the crisis of its history occurred. The next day it had increased in brightness a hundredfold and was doubling its bright-

ness in an hour's time. On the following evening, June 8, having increased another hundredfold, it was independently discovered within a few hours after it rose above the eastern horizon by a score of astronomers and amateurs in Europe and America. This remarkable example of the careful watch of the sky which is being maintained at all times leads us to believe that not many bright novæ have escaped observation in recent years. The outburst reached its maximum on June 10 when the star was equal to Canopus in brightness, being second only to Sirius itself. To know the real time of the outburst about 1,000 years must be subtracted from the date of its appearance, for the star is so far away that it takes that time for its light to reach us.

After its maximum the decline set in, but at a much slower rate than the rise. What was gained in brightness in the 2 days before maximum was lost in 200 days, and after that the decline was even slower. It took about 2 years to return to normal intensity after its 4 days of dissipation.

The spectrum showed remarkable changes of a character observed only in novae. At maximum, and presumably before, it resembled the spectrum of a hot, massive star but with the lines greatly displaced, indicating that the star was expanding at the terrific rate of over 1,000 miles per second. In spite of this immense expansion to a million times its original volume, the high temperature of over 10,000° was maintained so that the surface brightness did not change much until after maximum. The increase in light seems to have been largely the result of an increase in the dimensions of the star itself. The outburst was, in effect, an explosion.

Soon after maximum a gaseous shell was formed, which has continued to increase in diameter for nine years up to the present time. It now forms a neat ring of gas about the star similar to the ring nebula in Lyra, but about one-fourth its apparent size. Whatever may be the cause of the sudden outburst, we have observed in this case the actual formation of a ring or planetary nebula in an insignificant interval of time, astronomically speaking. A truly amazing phenomenon has taken place before our very eyes. The deliberate processes of celestial evolution have become a spectacle of activity and change, speeded up, as it were, so that in the minute span of time loaned to man for his mundane existence he may behold and ponder an example of the splendor of creation.

As the shell of gas is thrown off from the star at a speed a thousand times that of a projectile from a "big Bertha," the character of its radiation changes rapidly. In the emptiness of space, the atoms of the shell are cooled so that they would not be able to radiate at all were it not that the intense ether waves of the central star are continually bombarding them from behind and rousing them to

activity. The physicists tell us that the atoms are absorbing the ether waves which overtake them and are re-emitting the energy received in certain definite rays. Of course only the lightest elements are thrown out of the star, and the rays which we actually observe are those proceeding from hydrogen, helium, and nebulium atoms. This latter is a hitherto unknown gas which Bowen has recently shown to be merely oxygen and nitrogen, the elements so well known in our own atmosphere. They were not recognized previously because such rays could not be produced in the limited confines of the laboratory.

The cause of novæ outbursts, which are the most violent of all stellar activities, is still uncertain. We know much of the results of the explosion, but the underlying cause can only be conjectured. Possibly an encounter with nebulosity or another body may start the generation of internal energy in large amounts near the surface of the star. It can not be a deep-seated effect, for it is too sudden and ephemeral. The central portions of the star are probably not affected by the great display at the surface.

Only a few years later than Tycho's famous nova, the first periodic variable star was noted. In 1596 Fabricius, a Flemish clergyman, noticed that the red star Omicron in the constellation Cetus, the whale, was bright for a few months and then dropped below the limit of visibility. He doubtless thought it a nova. It was 40 years before its periodic character was discovered. Continued observation showed that it returned to maxima easily visible to the naked eye every 330 days; that it was visible about 5 months and too faint to be seen for 6 months; and that its rise to maximum was about twice as rapid as its decline. Because of its extraordinary behavior it was called Mira, the wonderful. This name it has richly deserved, for it continues to show peculiarities which can not be predicted and which are little understood. Its variations are somewhat uncertain but average about six magnitudes or two hundred and fifty fold increase from minimum to maximum light.

Although it received its name largely because of the surprise induced by its periodic character and its great range of brightness, its behavior as studied by the spectroscope has been even more wonderful, and it has perplexed observers since its spectrum was first observed more than 40 years ago. There are several facts in connection with the star and others of its class which are of special interest. Its apparent diameter is the largest thus far measured with the interferometer, and its real diameter, three hundred and fifty times that of the sun, is second only to that of Antares. If brought to our solar system and set in place of the sun, its boundaries would extend beyond the orbit of Mars, and the earth in its yearly motion would de-

scribe its orbit not much more than one-half the distance from the center to the circumference. If its mass were proportionately large, it would weigh twenty-five million times as much as the sun, and according to Einstein's theory its own gravitation would be so great that its light would be unable to leave its surface. The mass has not been directly determined, but it is probably about five or ten times that of the sun, instead of several million times. This low value means that we have an exceedingly large body with comparatively small mass, and the density comes out surprisingly low. It is, in fact, on the average for the whole star, only one ten-thousandth that of our atmosphere at sea level. The outer regions which we see have a much greater tenuity, for a star's mass is greatly concentrated toward the center. These regions are much nearer to a perfect vacuum than anything that can be produced in the laboratory. As far as our experience goes these stars are vast aggregations of nothingness. The poetical idea of tripping lightly from one star to another would be difficult of realization in such cases, for we might approach one of these giant bodies of gas and, except for the inconvenience of a rather torrid temperature of 2,000° or more, we might wander about indefinitely inside the star and not even know that we had arrived. If we wished to use an airplane, we should fall to the center of the star and yet find no place where it could support itself as it does in the air of the earth. At the surface, gravity is very small on account of the great distance from the center of the star. It amounts to only one-thousandth that on the earth. If one could get a solid footing there, he could jump to a height of a mile.

Mira and the other long-period variables are the coolest stars we know. The temperatures of the regions which we see vary with the brightness of the star from 1,600° to 2,500° centrigrade, absolute. Its red color is easily noted by the eye. A limit of stellar temperature seems to be set at this point below which stars can not exist, or if it it is possible to exist, they do not give out enough light to make their presence known to us. The temperature is so low that molecules of titanium oxide are able to form in the upper atmosphere. As shown by the bands in the spectrum, these molecules absorb some of the light from the interior and are partly responsible for the great light changes observed. As the star grows colder this absorption increases and so diminishes the light. The storing of the absorbed heat finally raises the temperature, the compounds become partly dissociated, and the star brightens.

Radial-velocity measures also indicate that the star expands and contracts during its period to the amount of 20 per cent of its radius, or about 30,000,000 miles. The cause of this pulsation is unknown, but it is sufficient to produce a distinct change in the effective temperature and a corresponding light variation.

There are a thousand or more variables of this type whose activities take place in periods of about a year. They are exceedingly interesting as being at the earliest stage of stellar existence; they are the youth of the skies, just stepping upon the threshold of celestial splendors. From the darkness of space they have suddenly emerged to take up their light-giving activities for billions of years.

In the 200 years following the discovery of Mira a few new variables, mostly of the same class, were discovered. It remained for two keen-eyed young men, friends and neighbors, John Goodricke and Edward Pigott, of York, England, to open the field of short-period variation of stars. Such variables, with periods from a few hours to 50 days, have been responsible for much of the knowledge which we now have concerning the properties and ages of the stars, their interiors, their distances, and the extent of the universe. Stars that are in action, such as variables, give opportunity to apply physical laws and deduce results as to the conditions prevailing there. They are the working laboratories of the sky where the astronomer may actually observe changing conditions. In our terrestrial laboratories we can vary conditions of pressure, density, and temperature for various sources at will to suit the investigation, but in the stellar laboratories we must depend upon the variable stars to make the manipulations for us.

Edward Pigott was the son of a surveyor who had some small astronomical instruments and had used them to observe the stars and planets. The son seems to have inherited his interest in astronomy from his father and was accustomed to make observations at his own home. His knowledge of the heavens attracted to him John Goodricke, the son of a neighboring lord, who is one of the most extraordinary characters in the history of science. Born a deaf-mute, he received, nevertheless, a good education and became especially proficient in mathematics. In 1782, when he was but 18 years of age, he took up the observation of Algol at the home of his friend, Edward Pigott. In a short time he had found its period of variation by comparing its brightness with that of near-by stars. Its variation was small, only 1.2 magnitudes, which makes the difficulty of observation very much greater than that of the variables of the type of Mira, where the variation is 5 or 6 magnitudes. He found the period to be 2 days 20 hours 49 minutes, which was so much shorter than that of any variable known before that the observation was doubtless looked upon with reserve by the scientists of the Royal Society to whom he communicated his results. In that early day, when physical double stars were scarcely known, he boldly concluded that the light changes were the result of an eclipse of the star by a darker companion which was describing an orbit about it in such an unexpectedly short time. It was 100 years before this remarkable

conclusion was verified by Vogel, who observed the star with the spectroscope and found that it was actually moving in an orbit in accordance with the theory. Two years later Goodricke discovered the variability of δ Cephei with an even smaller range (0.7 magnitude) of variability and deduced a period of 5 days 9 hours. He recognized it as a different kind of star, but he was not able to explain the cause of its variation, and we can do only slightly better to-day. In the same year he also observed β Lyræ, whose period is 12 days 22 hours and range 0.6 magnitude. It is also an eclipsing star, but the stars are so elongated toward each other that a variation is produced, independently of eclipse, by the fact that sometimes we see the stars endon and sometimes broadside. His friend Pigott discovered the variability of η Aquilæ in that same year.

Goodricke died in 1786 at the early age of 22 after discovering three variables which are to-day the type stars of their classes. Pigott later added two more, R Coronæ and R Scuti, and he also discovered two comets. Those who know the difficulty of the observation of variable stars of small range can not but admire the skill and persistence of these two young men who, on their own initiative, without instruments and without precedent, opened up in a systematic study the field of variable-star astronomy, the importance of which is being more clearly recognized as time goes on. Had Goodricke lived to the age proverbially allotted to the astronomer, what other fundamental discoveries might not have been his! Pigott continued his observations for a time after his friend's death, but later was lost to astronomical history.

The eclipsing stars of which Algol is the prototype are not intrinsically variable at all, but are binary stars whose orbits happen to be so placed that the components eclipse each other at certain times when viewed from the earth. They are always close together and their periods are usually short, from a few hours to a few days. Study of the light and velocity changes of such stars makes it possible to determine their masses, densities, absolute dimensions, surface brightness, and the distances between them; and these are the only stars for which these data may be directly calculated. About 300 eclipsing stars are known, most of which are found among the hottest and brightest stars. They represent the early stages of double-star existence, when the two stars are just being formed from a single body. They are often elongated toward each other by tidal effects, and in some cases may actually be in contact.

The Cepheids are named from Goodricke's star δ Cephei, which was the first known and the brightest of its class. They are single stars of great intrinsic brightness. They are the supergiants of the stars. Study of their light changes shows that they rise from mini-

mum to maximum much more quickly than they fall from maximum to minimum. The variation is usually a little less than one magnitude, the maximum brightness being about twice that at minimum. The spectroscope shows that the surface is heaving up and down with the period of the star's variation and that changes of temperature are taking place. Due to some unknown cause, the gaseous body of a star seems to have taken up a periodic pulsation of some kind, which accounts for the action observed there. If we assume with Shapley and Eddington that this pulsation is a free oscillation, the mass and density of the star may be computed. The period will depend largely on the density. Since the period may be observed with extreme precision, changes in the density, if present, might be deduced by investigating secular changes in the period. Such changes have not been definitely proved in the span of time during which these stars have been observed, which gives us an idea of the extreme deliberateness of stellar evolutionary processes.

Again, the periods have been found to be correlated to the luminosities, Cepheids with the longer periods having the greater intrinsic brightness. When proper calibration has been made, the luminosities and distances of Cepheids can thus be determined provided their periods are known. The great distances of the spiral nebulæ found by Hubble by this method are most interesting.

Some 300 stars have this general type of variation. The periods group about one-half day and 10 days. The longest known periods of this type are about 50 days. Those with periods near one-half day in length seem to form a separate group. They are of interest because they have the highest velocities of any stars known in our Milky Way system. One of them, called VX Herculis, is moving at a rate of over 250 miles a second, a speed sufficient to take it the whole distance from the earth to the sun in 4 days' time.

It may be doubted whether there are any stars which are entirely constant in brightness. Variation seems to be a relative matter. Nearly all very red stars appear to vary to a small extent in an irregular way. Our sun shows small changes in intensity of about 2 per cent, which seem, in general, to follow the sun-spot activity in an 11-year period, but with considerable irregularity. At certain times there are also fluctuations within a few days. The spots themselves, the faculæ, and the prominences are continually changing, and all affect, in some degree, the total amount of radiation given out. It is safe to say that activities of a similar nature could be found in the atmospheres of all stars, if we could get within observing distance; but they are probably more characteristic of dwarf stars of high density like our sun than of the tenuous giants.

The sun is the only star on which we can actually observe details of atmospheric activity. On account of its proximity we see its

surface as a disk of considerable size, and with the aid of the telescope we can examine the changes which are going on there. Sun spots are indicators of the presence of disturbances low down in the atmosphere of the sun. They are usually accompanied by faculæ which are areas of intense activity and high temperature. Even the fine structure of the solar disk is not at rest but is continually changing in the attempt to adjust itself to conditions within. The prominences projecting from the solar atmosphere are perhaps the most striking of all the phenomena of astronomy. At times they are thrown up to immense heights, as great as 500,000 miles, at speeds of 200 miles a second or more. Their rapid changes are most fascinating to the spectator, and their beautiful forms as seen in the deep red of hydrogen Hα are beyond description. With the spectro-helioscope recently devised by Doctor Hale, they can be splendidly seen even with a small telescope.

When we classify the stars, we find some hot, some relatively cool; some large, some small; and some light, some heavy. It is natural for us to ask the question as to what is the life history followed by stars in the course of their existence. The answer is not as definite as we might wish, because the process of change is too slow to be observed in the few years of man's history. It seems most likely that the solution will be found in connection with the density and mass sequence which has been observed among the stars. Apparently stars, in general, begin their visible careers under conditions of low density and great mass, as well as low temperature. As they contract their density increases and they become hotter, until a maximum is reached. Then they gradually become cooler again while continuing to decrease in size. Mass is lost throughout in the form of radiation. It may be that no one star follows the course outlined completely, but doubtless that is the direction of stellar progress. The actual process taking place in a star depends largely on the state of the atoms composing it. Very different behavior may be expected, depending on the extent to which the atoms are knocked to pieces and their rings of electrons removed.

We have not exhausted the story of the activities of the stars when we have considered merely their movements in space, their light variations, and the various disturbances which can be observed in their atmospheres. Recent advances in the interpretation of the behavior of the atom have been applied to the conditions within the stars. Eddington, by a process of masterly mathematical analysis, has given us a picture of the atomic activities in the interior of stars. He bases his conclusions on the known physical behavior of the atom in the laboratory and tests them out in the high temperatures of the stars. It is true that we can see down into the stars only a few

miles at most, but from the heat and light pouring forth it is possible to judge the conditions within. When we plunge below the surface, it will be necessary for us to change our proportions greatly if we are to get any idea of what is going on about us. In those regions we should no longer see the large surface disturbances, such as spots and prominences, which are measured in thousands and millions of miles, but all would appear calm and quiet as the depths of the sea. We would be aware only of increasing temperature and pressure as we approach the center. If, however, we might be diminished by some magic draft to one millionth of a millionth of our size or could see with a microscope that would magnify correspondingly, we should see a wealth of activity, and we should discover that within the stars atoms are moving about with speeds of 100 miles per second and knocking each other about in a most terrific fashion. We should be bewildered by multitudes of free electrons darting this way and that with vastly greater velocities. Electrons would be captured by atoms only to be shoved off again by powerful ether waves or X rays coming from below with the speed of light. The X rays would continue on their zigzag upward course, being absorbed and reemitted as they come in contact with atoms in their path. The atoms would be entirely stripped of their outer shells of electrons. After thousands of years, according to Eddington's computations, these rays finally reach the surface, and their energy is taken up by the cooler atoms and sent out to the corners of the universe as light. Traveling in straight lines for many years they may fall upon our tiny earth and tell to eager scientists the story of their origin and escape.

In spite of this indescribable confusion, there would be equilibrium in the mean at any point within the star. The knocking about of the atoms and electrons and the outward pressure of radiation, mostly in the form of X rays, would be just sufficient to support the outer layers against the force of gravitation, and thus keep the star from complete collapse. These laboratories of the sky are the scenes of action beyond anything which we know in the coldness of our earthly surroundings. They seem strange and mysterious only because we do not fully understand the processes involved and because we have been accustomed to an entirely different scale of dimensions and temperature.

We have passed rapidly from the movements of the stars, which are the greatest aggregations of matter in our universe, to the mechanism of the atom, which is the smallest complete unit of matter. Our measurements have changed from thousands of light-years for the distances between the stars to a billionth of a billionth of a second, which is the time it takes light to cross the orbit of an electron. The

velocities have varied from the secular contraction of the giant stars to the velocity of light which Doctor Michelson finds rushes from Mount Wilson to Mount San Antonio and back more than four thousand times a second. The masses vary from thirty million times that of the earth for the most massive stars to 10^{-50} of the earth's mass for an electron.

Yet, in spite of the great diversity of time and space, we find all matter behaving in an orderly fashion. The activity which is found everywhere is controlled by the fundamental laws of nature, which work in the same way, so far as we know, in the stars as on the earth. In searching out the mechanism of unknown action in the universe, whether large or small, the scientist finds his pleasure and privilege. His satisfaction is vastly enhanced if, in addition to noting some significant occurrence, he can come to understand the underlying laws governing its action.

ISLAND GALAXIES [1]

By A. Vibert Douglas, M. B. E., Ph.D.

McGill University, Montreal

[With five plates]

The knowledge that the heavens contain bodies that are neither planets nor stars is age old, for the keen eyes of the stargazers of civilizations long since gone did not fail to detect such objects as the nebulosity in the constellation of Orion and the small, hazy patch in Andromeda. But the significance of these objects remained a mystery for many centuries.

With the invention of the refracting telescope by Galileo about 1600, many of the apparently nebulous regions in the Milky Way were found to be resolvable into separate stars. These are so closely strewn in the sky that to the unaided eye their light is completely merged and blended. Toward the end of the seventeenth century the second great type of telescope was devised by Sir Isaac Newton, namely, the reflecting telescope, in which the starlight is brought to a focus not by a lens but by a mirror. About 150 years later, when the small pioneer telescopes of Galileo and Newton had given place to large and powerful instruments, Lord Rosse discovered that a certain nebulous region in the constellation Cannes Venatici when viewed through his great telescope was not merely a random, haphazard agglomeration, but a cluster of many stars distinctly grouped in the configuration of a spiral. (Pl. 5.) Thereafter the search for and discovery of other spiral nebulæ became one of the most fruitful tasks of the astronomer. From that time to the present, as a result of ever-increasingly powerful instruments, together with the introduction of photographic methods, many hundreds of spiral nebulæ have been found, and it is estimated that a thorough search of the entire heavens would disclose hundreds of thousands of them.

Speculation was at once begun. Could it be that all the nebulæ were in reality close assemblages of stars requiring only yet more powerful telescopes to show each star separately?

---

[1] Reprinted by permission, with alterations, from Discovery, Vol. IX, No. 99, March, 1928.

Sir William Huggins gave the decisive negative answer to this question—some of the nebulæ may be great clusters of stars, but there are others truly named nebulæ, for they are masses of glowing gas having the type of spectrum typical of gas whose atoms are radiating their characteristic quanta of energy.

Such is the nature of the great nebula in Orion and of many other nebulæ where vast regions of space are sparsely filled with gaseous matter. Where these gases are sufficiently excited they radiate the distinctive wave lengths of light associated with the atoms and molecules of which they are composed. Thus the spectroscopist identifies in these nebular spectra the unmistakable radiations of hydrogen and helium, often also nitrogen and carbon, and in addition to these he finds intense radiations which until recently were attributed to an unknown substance called nebulium. The mystery is now solved by Doctor Bowen, California, who attributes these radiations to oxygen and nitrogen atoms, radiating in an unusual manner as a result of their ionized condition and the low density of the nebulæ.

The gaseous nebulæ are not all sufficiently hot to radiate; some of them glow only because of the proximity of very bright hot stars; others are so cool that they absorb all the starlight that falls on them, thus forming great black patches in the sky. A famous dark nebula in the region of the Southern Cross is known as the "coal sack." A great American observer, the late Professor Barnard, made a systematic study of these opaque clouds, of which he listed over 180, varying from very small patches with sharp outlines to the long, irregular "dark lanes" so striking a feature of the constellation of Ophiuchus.

We know, then, that of the celestial objects originally called nebulæ some are vast clouds of gas occupying regions of space compared with which our solar system is absolutely insignificant; others are clusters of stars; while yet others, in particular the spiral nebulæ, are composed of both stars and gaseous nebulosity.

For a long time no one had any conception of the immensity of spiral nebulæ. They were thought of as comparatively small aggregations of stars within the great assemblage of stars surrounding our sun in all directions. The authors of the planetesimal theory drew an analogy between the arms of a spiral nebula and the arms of gaseous matter which they assumed to have been drawn out from the surface layers of our sun by the tidal forces produced by a passing star, these disrupted arms giving rise to the several condensations of matter which eventually became the planets of the solar system. Gradually, however, it became apparent that a spiral nebula was not to be compared with the solar system, but rather

with the whole galaxy of stars—our sun and the thousand million other suns which stud the heavens all around us.

There are known to be many thousand spiral nebulæ, and if each be comparable in size to our whole stellar galaxy it is obvious that they are not within it. They are in fact *island galaxies*. The term is here used to denote exactly the same thing as the term "island universes," which has become so common an expression in American astronomical writing. Since "universe" is defined as "all that exists, the creation and the Creator," its use in the plural seems unfortunate, especially as the word "galaxy" is quite adequate. Dignifying our stellar system by the name "*the* galaxy"—not merely because it is the system to which our sun belongs but for the more logical reason that as yet no other aggregation of stars is known to be quite as large—it then becomes natural to divide all nebulæ into two main classes, termed, respectively, the "galactic" and the "extragalactic" nebulæ.

Our galaxy is a gigantic aggregation of stars and gaseous nebulæ. It comprises all the stars visible to the naked eye and the many thousands more revealed by the telescope when used visually. These numbers are multiplied manyfold by the use of photography when stars so faint or remote as to be invisible leave the impress of their images upon the sensitive plate after many hours of exposure. The study of these photographs, counting the numbers of the stars of different magnitude or brightness and comparing the numbers in different parts of the sky, has shown that it is possible to make an estimate of their number and a representation of their distribution in space.

Even with the unaided eye it is evident that the distribution of stars is not spherically symmetrical. All along a great circle in the heavens the stars are more numerous than elsewhere, and this encircling band is called the Milky Way. The photographic plates reveal the same concentration, and so the Milky Way is called the galactic plane, while the directions at right angles to this plane, where the stars are less numerous and on the average less distant, are termed the galactic poles. Our sun happens to be situated not far from the center of this great lens-shaped cluster of stars. The dimensions of the galaxy are so vast as to be best appreciated when expressed in light-years, the unit so frequently employed by astronomers, equivalent to nearly 6,000,000,000,000 miles. Our galaxy is approximately 100,000 light-years across the galactic plane and about one-fifth as much measured toward the galactic poles.

In this vast region, at great distances one from another, there are 30,000 million stars, according to the most recent calculations of Seares and van Rhijn as reported by Dr. C. G. Abbot of the Smithsonian Institution, Washington. As these are by no means equi-

spaced, there are concentrations of stars here and there which, seen from another part of the galaxy, produce such beautiful effects as the "star clouds" in Sagittarius or the "globular clusters" in Hercules and other parts of the sky. Within the galaxy, too, filling great regions of space around and between some of the stars, are the gaseous nebulæ both dark and bright.

Returning now to the extragalactic nebulæ—the great gaseous objects and star clusters like islands in a three-dimensional ocean of space beyond the Milky Way—we are indebted to Dr. E. P. Hubble of Mount Wilson Observatory for much new knowledge concerning them. In a recently published paper [2] he has given the results of a careful study of 400 such nebulæ. Some of the extragalactic nebulæ show no regularity of shape or structure. These form a subclass by themselves, and to this class belong the Magellanic Clouds, great irregular star clouds visible from the Southern Hemisphere like detached portions of the Milky Way, though actually as far away again. Far more numerous than the irregular nebulæ are those having a definite shape or structure, the ellipsoidal and the spiral nebulæ. The spectra of the former are so similar to the solar spectrum that there is no room for doubt that they are clusters of stars, even though the individual stars can not be photographed. Possibly the stars are being gradually condensed out of the gases of which the nebulæ were composed, and the residual gases act as envelopes rendering the star images indistinct.

Some of the nebulæ are apparently at a transition stage between ellipsoidal and spiral, while yet others display well-developed spiral arms. The evidence seems strongly to point toward an evolutionary process, as a glance at the illustrations will make clear—the gradual unwinding, the appearance of stars and star streams, the whole vast process of the development of island galaxies.

With this idea of progressive development in mind, the spiral nebulæ are said to be of early, intermediate or late type, according as they present the appearance of the uncondensed nebula in Plate 1, or intermediate forms between that and the well-developed, far-flung, stellar arms so clearly shown in Plates 4 and 5.

The distances of some of the spirals have been determined in a very interesting way. These spirals contain stars, known as Cepheid variables, whose light is not steady but fluctuates with perfect regularity, falling slowly from maximum to minimum and then rising rapidly to maximum. The light cycles usually have periods of a few hours or a few days. When studying similar stars whose true brightness was known, Miss Leavitt of Harvard Observatory discovered the fact that the longer the period of light variation the

[2] Extragalactic Nebulæ. E. P. Hubble. Astrophysical Journal, December, 1926.

greater the intrinsic luminosity of the star. This relation was well established for the less distant stars, and it seemed so logical to expect stars with identical characteristics to obey the same law, whether near or far, that it has been applied to stars in these remote galaxies. From a series of photographs the period of light variation is found, then the established relation gives the true luminosity, and this, together with the apparent brightness on the photographs, gives the necessary data for calculating the distance.

It was by this method that Hubble determined the distance of the great nebula in Andromeda (Pl. 3) to be more than 900,000 light-years. Another very large, bright spiral in the constellation of Triangulum was found by similar means to be at about the same distance. It is believed, however, that the thousands of fainter spirals are very much more distant. In Plates 1 and 2 are shown two of the spirals in the region of the heavens designated by the constellation named Coma Berenices. Here, and in the adjacent region of Virgo, spiral nebulæ are richly strewn on photographic plates of long exposure, and both Hubble and Shapley have estimated for some of these no less a distance than 100 million light-years.

In spite of these tremendous distances much can be learned about the island galaxies, though, of course, the farther away a galaxy is the less up to date will be the news which the light brings. Thus in the case of the Andromeda nebula, approximately 1,000,000 light-years distant, the rays of light which produced the image on the negative of Plate 3 had been traveling through space for 1,000,000 years, and consequently the picture we see is not the Andromeda nebula as it is to-day but as it was 1,000,000 years ago.

Just what it is like now we can only conjecture—probably not so very different from the picture, for 1,000,000 years is less in the life of a star than 1 second of time in the average life of a man.

The radial velocities of the brighter nebulæ can be determined by means of the spectroscope and show that they are moving through space with great velocities. The Andromeda nebula is approaching our galaxy with a velocity of 300 kilometers per second. Most of the spirals, however, are receding at speeds averaging 600 kilometers per second.

There are two ways of endeavoring to find out the total mass of a galaxy, and when two quite independent methods lead to results which are in good agreement the astronomer feels considerable confidence in the reliability of his calculations. The first method is based upon a speculation regarding the ratio of luminous to non-luminous matter in a galaxy and the theory that the luminosity is determined by the mass. When the absolute luminosity of a galaxy is known, its total mass can therefore be calculated. This method

24034—29——14

has been used by Opik and gives for the Andromeda nebula a mass nearly 2,000 million times the mass of an average star like our sun. The second method depends upon the spectroscopic determination of the line-of-sight velocity of opposite edges of the nebula. If one side be found to be approaching and the other side receding, the only logical conclusion is that the whole nebula is rotating. Now, a rotating mass will fly asunder by centrifugal force unless some equal and opposite force holds its members together. If gravitation, acting toward the center of the nebula, provides this balancing force, it is possible to calculate the total mass necessary to give rise to the restraining force required. The period of rotation of the Andromeda galaxy was found to be 17,000,000 years. From this its mass was calculated, giving just over 3,000 million suns. The agreement with Opik's result is satisfactory.

Our picture of this best-known island galaxy can be briefly summed up in a few words: A thousand million stars—like those in our own galaxy, some larger and some smaller than our sun—and much uncondensed gas, all forming the giant spiral nebula traveling through space at least 300 kilometers per second, and as it travels, slowly expanding and unwinding its spiral arms, while as a whole it is turning round with solemn, majestic deliberation.

THE EINSTEIN UNIVERSE

Men of science throughout all the ages have been obsessed with the idea that there is order in the universe. When the great wave of agnosticism passed over Europe, threatening to sweep the thoughts of men from all moorings, this fundamental tenet of scientific faith was the sheet anchor which saved mankind. So deeply implanted is this belief in natural law and order, that when some facts of astronomy and physics appeared to be incompatible with the current conception of the Universe, based as it is on the stately geometry of Euclid and the Newtonian mechanics, men of science were willing to consider throwing over the old conception and adopting a new conception suggested by Einstein. This willingness is the more remarkable when it is remembered that, to the nonmathematical mind, the four-dimensional space-time universe of Einstein seems mysterious, fantastic, and unreal. Yet there is already considerable evidence in its favor, and so, generalizing from his detailed study of 400 galaxies, Hubble proceeds to evaluate the radius, volume, and mass of the Einstein universe.

He calculates first the average density of space. If the matter forming all the stars and gaseous nebulæ in our galaxy and in the 400 other galaxies studied by him were to be spread evenly throughout the space occupied by these galaxies, there would be a density of matter equivalent to one atom of hydrogen in every 300 cubic feet.

He then evaluates the radius of curvature of space time, which, according to Einstein, depends only upon this average density and two constants, the velocity of light and the gravitational constant. This radius comes out to be 5,000 million million astronomical units (5×10^{15} times the sun-earth distance). This value is a thousand times greater than that calculated by Silberstein from other relations and other data available three years ago. Here, perhaps, in reality, as always metaphorically, the horizon recedes as knowledge increases.

What then is the total amount of matter distributed as stars and nebulæ, in clusters and in galaxies, throughout this vast yet finite universe? To express these figures in words is far too cumbersome, and so we set them forth in the elegant shorthand used always by the physicist and the astronomer: If M be the total mass of matter in the Einstein universe, then

$$
\begin{aligned}
M &= 1.8 \times 10^{57} \text{ gms.} \\
&= 9.0 \times 10^{22} \text{ suns} \\
&= 3.5 \times 10^{15} \text{ normal galaxies}
\end{aligned}
$$

In other words, there are about 10^{51} tons of matter, and were this to consist only of hydrogen there would be 10^{81} atoms.

How much real value these stupendous figures have it is impossible to say. Firstly, they involve the Einstein conception of the universe, not yet indisputably established.[3] Secondly, assuming that the Einstein universe has a real significance, these figures are conclusions regarding a universe not one ten-millionth of whose volume can be explored by even the giant telescope at Mount Wilson Observatory. If the distance of a galaxy exceed only one six-hundredth of the radius of curvature above mentioned, no telescope yet constructed can detect it. But a man will judge the world of humanity, their habits and characteristics, their comings and goings, by his knowledge of a few score individuals and his passing glimpses of a few thousand, and his conclusions will not be entirely valueless. So, too, the astronomer, with reliable knowledge of hundreds of stars and many nebulæ, and glimpses of thousands yet more distant, will not refrain from speculation regarding the vast regions as yet beyond his ken—the ocean of spacetime studded with 1,000 million million glorious island galaxies.

---

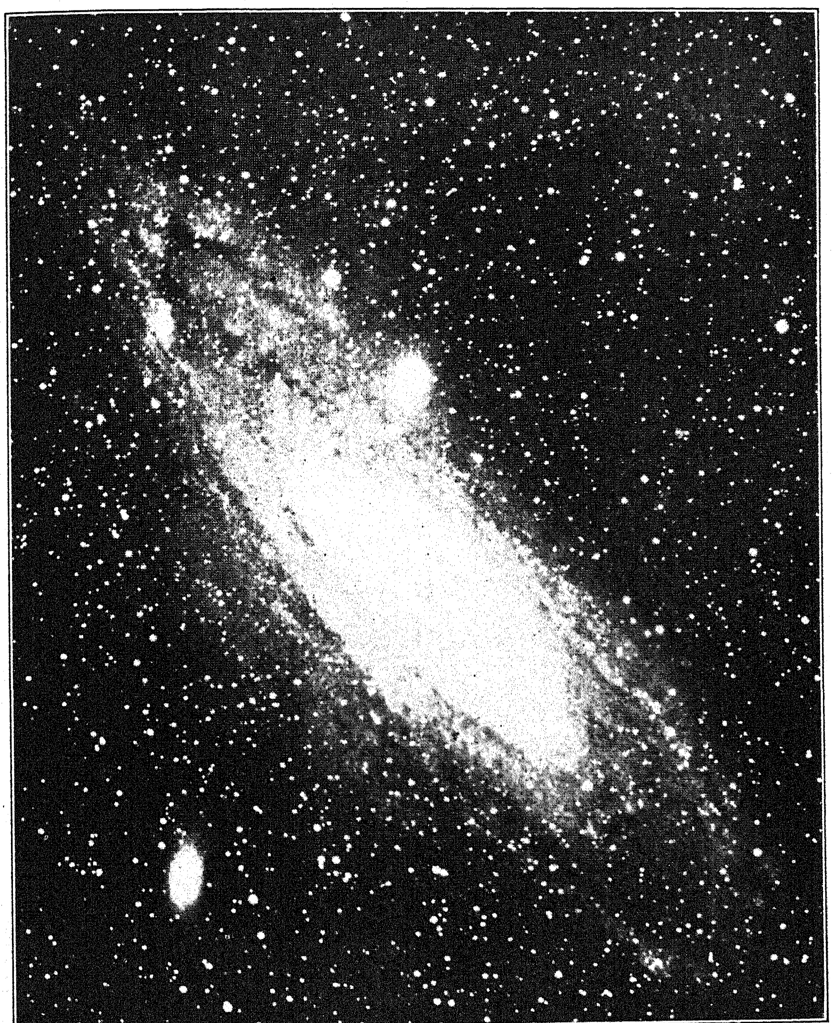
[3] Indeed there are many who reject the Einstein cosmology in favor of the modifications proposed by de Sitter, modifications which obviate some of the difficulties inherent in Einstein's cosmology. Doctor Silberstein, for example, denies any reality to the above figures, retaining confidence in his own value of the radius of curvature based upon his deductions from the de Sitter equations.

ISLAND GALAXY (M. 64)

An early type spiral nebula in the constellation Como Berenices

ISLAND GALAXY (H. V. 24)

Edge-on view of a spiral nebula in the constellation Coma Berenices. Five hours' exposure. Foreground stars are in our Galaxy and the brighter ones are distorted by overexposure



THE GREAT NEBULA IN ANDROMEDA (M. 31)

One of the least distant of the Island Galaxies, just visible to the naked eye; it is made up of some thousand million stars and much gaseous matter, and it is the best known of these bodies

SPIRAL NEBULA (M. 101)

A very beautiful Island Galaxy in the constellation Ursa Major. Four hours' exposure

THE WHIRLPOOL NEBULA (N. G. C. 5194-5)

This spectacular spiral in the constellation Canes Venatici was first carefully observed by Lord Rosse and seen to be not merely a mass of glowing gas but an aggregation of many stars

ASTRONOMICAL TELESCOPES[1]

By F. G. Pease

[With seven plates]

Whenever one looks at any object, the crystalline lens in the eye forms an image of that object on the retina. To see a distant object more plainly and bring it apparently closer, it is necessary to enlarge this image. The instrument which does this is called a telescope. It consists of two optical parts and a mechanical rod or tube to hold them at the proper distance apart. One of the optical parts, which may be either a lens or a mirror, forms an image near the eye, and the other, called the eyepiece, magnifies it. A telescope in which a lens forms the image is called a refractor; one in which a mirror forms the image, a reflector. The size of the image is determined by the focal length of the lens or mirror, and the brightness of the image by its area.

The first telescope of definite record was made by Lippershey in Holland when he placed a spectacle lens at each end of a tube, and made terrestrial observations by holding it in the hands or by resting it upon a stand to steady it. Astronomical observations had, of course, been made long before, at first with the naked eye, then with simple measuring sticks held at arm's length, to be followed by apertures cut in walls, or markings placed on ramps to observe certain stars. As time passed, the use of graduated circles became common practice, and just preceding the advent of the telescope came the type of quadrant described by Hevelius and shown in Plate 2. The observer sighted the star through the two markers upon the movable bar which he adjusted up and down, at the same time rotating the whole quadrant about the vertical post. All that could be done with these instruments was to chart the relative positions of the stars and planets with respect to one another.

Upon learning of Lippershey's "optic tube," Galileo constructed such a telescope of two spectacle lenses and a paper tube, and from

[1] A lecture delivered on Dec. 15, 1927, at the Public Library, Los Angeles, under the auspices of the Astronomical Society of the Pacific. Reprinted by permission, with additional illustrations, from the Publications of the Astronomical Society of the Pacific, Vol. XL, No. 233, February, 1928.

his tower in the hills of Florence, Italy, turned it to the moon and the planet Jupiter. What he actually saw was but little compared with what we see to-day, but it was sufficient to stir the foundations of thought to their very depths. Here was another world with mountains and seas like the earth, and here another planet with not one, but four, moons circulating around it. We are likely to think of these developments as ancient history, yet the telescope is a very recent tool of man, its advent being coincident with the settling of America's eastern coast. Sixty-seven years had passed since Cabrillo had sailed these California shores, Pocahontas had just saved the life of Capt. John Smith, and the Pilgrims had not yet embarked in the *Mayflower* when Galileo made his first telescopic observations in January, 1610.

Telescopes continued to be made, and though there was little progress in astronomical observations aside from charting the features of the moon, sun spots, and the like, the telescope itself was developed into a highly useful instrument, a step necessary before its best work could be accomplished. The lens was first mounted at the upper end of the quadrant bar and the eyepiece at the lower end. This type of instrument necessitated two motions, and it was soon found that by tipping the post to point to the north pole of the heavens, a single motion about the post would keep the star in view, the post now being called the polar axis.

In this tipped or equatorial instrument the quadrant arm is developed into a tube with an axis through its center. This axis is called the declination axis and is adjusted once for all. There are many variations in the mechanical forms of the axes. In the English type of mounting, for example, the polar axis is a yoke with bearings at either end, with the tube swung between its sides. In the German type, of which the 36-inch Lick telescope is an example, the declination axis is attached to the upper end of the polar axis, the tube being fastened at one end of the declination axis and a counterweight at the other. In the forked type, as illustrated by the 60-inch reflector on Mount Wilson, the upper end of the polar axis above the two bearings is forked, either prong carrying one end of the declination axis. In the turret type of telescope, with which Governor Hartness, of Vermont, has spent many a delightful night, the polar axis is merged into the roof of the observatory, the light being reflected into the turret by a 45° mirror placed at the intersection of the declination axis and the tube.

Having at first only simple lenses to work with, astronomers found that if they wished to increase the size of the lens they must at the same time increase its focal length. One of Huyghens' lenses, for example, was 6 inches in aperture and 210 feet in focal length. These

huge telescopes were swung from braced poles by tackle, and from the pictures we judge that a sight through one of these monsters was quite a social event. All lenses are subject to faults called aberrations, and it was partly because of these and partly because of the poor glass made in those early days that astronomers had to make use of this type of telescope.

Newton, whose name is familiar to us all, believed that these aberrations could not be removed, and consequently turned his attention to mirrors. His first model was presented to the Royal Society of London in 1672. Though this telescope itself has rested idly on the shelves since that time, its spirit has moved in continuously increasing waves through the Herschels, through Lord Rosse, and through Common, culminating in the beautiful mechanism we have in the 100-inch Hooker reflector on Mount Wilson. Newton's mirror is made of a bronze called speculum, a heavy metal, very brittle, which whenever it tarnishes must be polished anew in the optical shop.

Herschel, a musician at the English watering resort of Bath, made many of these mirrors with his own hands, his largest telescope having a mirror 4 feet in diameter and a tube 40 feet long. The observer stood at the upper end and looked down into the tube, the large mirror being tipped so as to throw the image to one side. With his telescopes Herschel discovered many nebulæ, double stars, and the planet Uranus.

Zeal such as that of Herschel and his son, John, was also found in the two great Irish gentlemen, Grubb and Lord Rosse. With no other help than the workmen on his farm the latter accomplished a prodigious amount of experimental work on metals, mirrors, and methods of casting them. Telescope mountings of various sizes culminated in his 6-foot reflector, with which he discovered that many of the nebulæ, of which Messier 51 is an example, are of a spiral character, his drawing outlining the principal features portrayed in our photographs to-day. As a further indication of his versatility, it may be mentioned that it was Lord Rosse who advised the English Navy to protect its ships with armor plate. This innovation, however, like many others, was too early for the times.

Meanwhile a way had been found to improve the lens, and Dolland had made his achromatic objectives. Then Fraunhofer, a German genius, having been taught how to make glass by the younger Guinand, succeded in casting several fine pieces of glass and fashioning them into a lens of very high precision, the curves for which he calculated himself. We can picture Fraunhofer in his laboratory making his disks of glass into prisms and lenses and then passing the rays of the sun and a few of the brighter stars through his

spectroscope, discovering the numerous dark lines now known as the Fraunhofer lines.

Through the addition of a means for moving the telescope continuously in right ascension, the mechanism reached a state in which the observer could devote his thoughts and attention solely to his work, and a great increase in the accuracy of measurements resulted. Most telescopes are turned with a mechanical driving clock, but

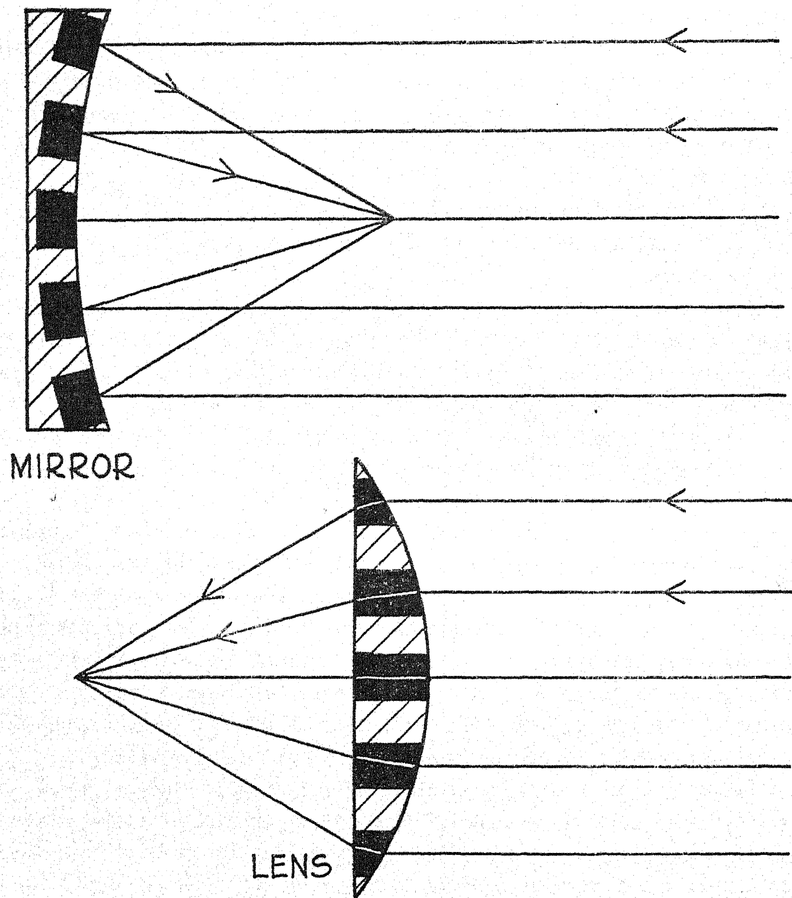


FIGURE 1.—Action of a lens and a concave mirror on parallel light

to-day some are electrically driven. In the mechanical clock the essential parts are a falling weight or an unwinding spring whose rate of descent or release is regulated by a governor through a train of gears. Foucault designed many of these governors, but the principle in all of them is the introduction of a slight amount of resistance to regulate the fall of the weights. The governor used in all our telescopes on Mount Wilson is patterned after the one designed by

Warner and Swasey for use in their large refractors. Years of use have proved its superiority to any others we have yet tried.

Perhaps the final factor which enables us to build the large instruments we have to-day is the silver-on-glass mirror. The fact that we can take a piece of glass such as the 100-inch disk and cut the curve in its surface once for all is a matter of very great importance. The glass forms the permanent curve, but it is actually the very thin silver film that is the opaque reflector. Unlike the speculum mirrors, the reflecting surface is very easily replaced without the least injury to the curve or the mirror disk itself. The silvering of the 100-inch disk, for example, is accomplished by removing the mirror in its cell from the telescope and lowering it by an elevator into the silvering room below. A metal band is wrapped around the edge of the mirror, forming a vessel or bowl. The old silver film is removed with acid, the mirror is washed, and then a fresh film precipitated from a solution poured into the bowl. Waste solutions are drained off through the spout into a large tank below. A thorough burnishing with chamois skin and rouge removes from the film any trace of whiteness which may form during the silvering.

Let us now study the optical parts of a telescope in order to understand them a little better. We have two methods of forming optical images. In one the light passes through a transparent lens, while in the other the material is opaque and light is reflected from its surface. We take advantage of the fact that light travels more slowly in transparent solids than in air and that by placing different thicknesses in the beam we can retard one portion with respect to another. To form an image, all the rays in a parallel beam must reach the focus at the same time. As illustrated in Figure 1, the outermost ray naturally has to travel a greater distance, so very little glass is put in its path. A little further in, the beam is not bent so much; hence the angle of the prism is made less, and at the center the glass has parallel surfaces. Notice that as we approach the center we make the glass thicker and thicker. If we were skillful enough, we could take a very large number of pieces of glass and place them together; but we can do still better—we shall use only one piece of glass and make the surfaces such as to imitate the action of all the individual prisms. For our ordinary lenses the curve we use is a sphere, as it is most easily made with our grinding tools.

In the case of a mirror (fig. 1) we want the parallel light to reach the focus by equivalent paths, so we take a number of small mirrors and place them so that all the total distances are the same. Notice that the outer ones are brought forward a little and tipped differently with respect to one another and to the inner one which is squared on. If we should replace the small blocks of glass by a single piece and grind a surface to imitate the action of the separate

mirrors, the resulting curve would be a paraboloid, and it is this surface which our amateurs are seeking when they attempt a perfect mirror.

Light of all colors is reflected by a mirror at the same angle, so that the image appears in natural colors. In passing through a single lens, however, the blue or shorter wave lengths are bent more than the red rays and come to a shorter focus. This defect, called chromatic aberration, makes the image formed by a simple lens not a single clear picture but a sharp image of one color surrounded by a halo of all the remaining colors. The reader can see this for him-

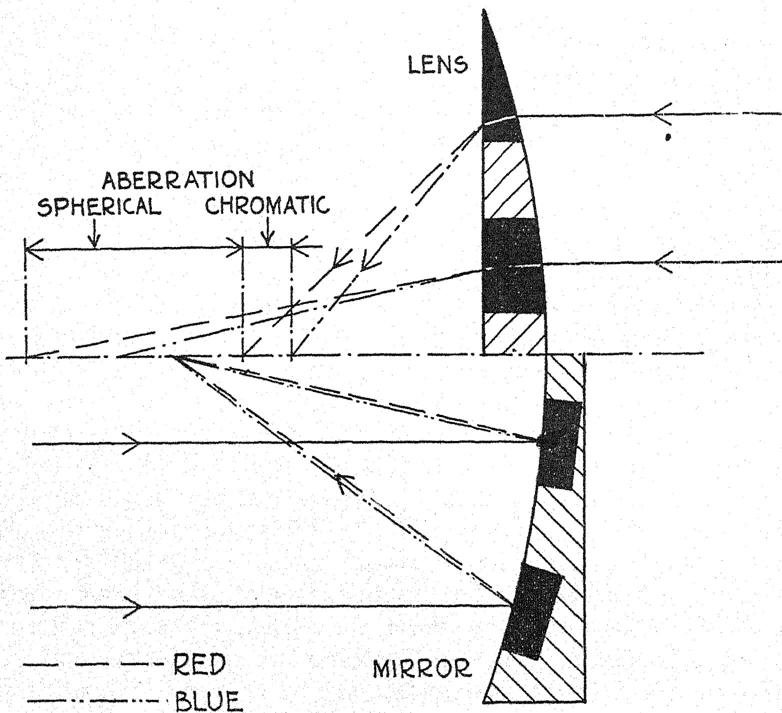


FIGURE 2.—Aberrations of a lens

self by holding a reading glass between an incandescent lamp and the wall and moving it slightly back and forth.

A single lens with spherical curves has also another defect which we call spherical aberration. If you cover first the center, then the rim, of your lens, you will find a difference in focus for images even of the same color. By choosing the proper curves this difference can be greatly reduced. Both of these aberrations require a second lens to bring the multiple images to a common focus.

To-day we may choose from the glass manufacturers' lists two glasses which have nearly the same relative dispersion or spreading

of the spectrum, but which deviate or bend the rays by different amounts. Two prisms of like material and angle can be placed so as to produce a colorless beam, but they will have no power of altering the initial direction of the beam. Two prisms of unlike materials and different angles properly chosen will produce a nearly colorless beam and still have the power of converging the rays to a focus. By expanding these prisms into a convex and a concave lens we obtain an achromatic lens, giving an image practically free from color.

The central image formed by a paraboloidal mirror is perfect, but near the edge of the field of view the images are elongated toward the center. This defect—coma, as the optician calls it—limits the size of the picture, but until further improvements are made we shall continue to use the paraboloidal reflector for large telescopes.

To-day the telescope is more than the simple instrument through which one looks at the heavens. The only way in which we can make contact with the stars is to gather the radiations which they send us and study the messages they bring. The lens or mirror gathers these radiations and with them forms an image. This image we examine not only with the eyepiece but with all the modern auxiliary attachments such as plate holders, spectrographs, photometers, and bolometers. With them we can learn many facts about the stars, their chemical composition, sizes, masses, and densities, their distances and shapes, their temperatures and their ages, and how much longer they will probably live.

Much of the work formerly done with the eyepiece is now accomplished by photography. The telescope is a huge camera, the tube being the camera box. The eyepiece having been removed, the plate is placed directly at the focus where the various parts of the image affect it according to their brightness. Exposure times vary greatly; some for photometric work are of but a second's duration, while those for a star cluster may continue for 8 or 10 hours. Photographs of the moon and planets take from a half second to several seconds, and more if a color screen is used. One advantage that the photographic plate has over the eye is the ability to accumulate the effects of the light. Our pictures of nebulæ accordingly show marvelous structures not visible in the eyepiece.

The second far-reaching event in the history of astronomy took place when Sir William Huggins attached a spectroscope to his telescope and viewed the spectrum of many stars. The telescope alone taught us that there are other worlds than ours; the telescope and the spectroscope together, that all these worlds are made of the same materials as the earth.

Spectroscopic work developed rapidly, and to-day more than half of all astronomical observation is in this fascinating department. From the spectrum one learns practically all that he could learn were the star in his own laboratory; even more, for there are stars whose temperatures exceed any we know on the earth, and in studying these fiery caldrons the astronomer finds many a strange and often uncanny result. He discovers materials so vanishingly thin that our lowest vacua are very high-pressure affairs by comparison; materials so heavy that a cubic inch weighs a ton. He tells us of the extraordinary velocities with which some of the celestial bodies move, for example, the whirling nebula in Virgo. A spectrum exposed for 80 hours shows the nebula receding at a velocity of 730 miles a second, while at the same time it is spinning around with a velocity of 205 miles a second at a point 2 minutes of arc from the center.

To measure the total energy of the stars, a thermocouple or bolometer is used, and readings are automatically recorded on moving plates.

The Michelson interferometer is the most recent instrument added to the telescope, and with it we measure the diameter of the stars. A large steel beam carrying four mirrors is placed at the upper end of the tube. The whole end of the tube is covered except for two apertures underneath the central mirrors. The observer sits at the eyepiece (see pl. 1) manipulating a small glass wedge until dark lines appear across the star's image. As he gradually separates the outer mirrors on the beam these black lines or fringes disappear. Measuring the separation of the mirrors, he calculates the angular size of the star, and knowing its distance he computes its linear diameter. The first star thus measured was Betelgeuse, the bright red star in the right shoulder of Orion. It proved to have a diameter comparable with that of the orbit of Mars, but by measures of Mira and Antares has since been given third place in size.

For solar work many telescopes are of small aperture and long focal length. In the horizontal telescope the tube is laid along the ground, so to speak, and sunlight is reflected into it all day by a rotating mirror called a coelostat. In the 150-foot tower telescope on Mount Wilson the tube stands vertically, however, and the light is directed through it by mirrors at its upper end. The observer works in a house at the foot of the tower, while below him is a pit 80 feet deep in which the spectrograph is placed. The image of the sun formed by this tower telescope is 17 inches in diameter, and the spectrum produced by its spectrograph is 20 feet or more long. The sun is a vast globe of incandescent gases having a temperature at the surface of about 6,000°. Metals and other substances which are solids on the earth appear there in the form of vapors, and vast

storms sweep the surface. These storms, called sun spots, are so huge that the earth would be lost in some of them.

Those of us who spend not only the long watches of the night but weeks of nights exposing the same plate upon the same object realize what a great boon it would be to obtain these same photographs in a much shorter time, or rather to spend the same time upon a spectrum of greater scale or upon fainter stars and nebulæ about which we have comparatively little direct knowledge. No search for the pole could be of more interest to the explorer than are the problems of celestial objects to the astronomer. Many of them are so far away that our telescopes are not powerful enough for us to decide whether they are clusters or nebulæ, but we shall not rest satisfied until we learn their true character. Back in the seventeenth century Hevelius made drawings of the moon, engraving nearly 100 of them on copper plates himself, showing the moon at its various phases. Note the accuracy of his drawing, Plate 4, Figure 1, so far as general features are concerned, the streaks radiating from some of the craters, the dark seas, the mountain ranges, and compare them with our best photographs to-day. We will admit that the photographic portrayal of the moon's features is splendid and that when we look at an individual crater such as Copernicus the amount of detail is great. But imagine that we could step into Jules Verne's projectile and pay a visit to the moon, see it closely with its rills and valleys, its craters and mountain peaks. Would it not be worth the while? Actually we can not do this at present, but we may get all the thrills by building a telescope of greater aperture which will bring the image of the moon nearer to us.

For many years we have been studying the problems of very large telescopes. With the interferometer we have examined atmospheric disturbances over regions 20 feet in diameter and can definitely say that there is very little difference in the effect on the image between beams of starlight 4 feet apart and 20 feet apart. Experience in building our present machines and designing still larger ones shows that the construction of such telescopes is, with all the increased facilities of to-day, but a piece of straightforward work, no more difficult than were others in their day.

Machine shops are equipped with tools of ample capacity to finish all required parts of large size or weight. Powerful cranes will lift our materials and place them at our command. Precision bearings of a size we need have already been tried on our 14-inch seacoast guns and found to stand all that we ask of them. Many times you have seen trucks, carrying large safes and castings, guns, and turbines, rolling along our streets as though the movement of a weight of 100 tons were an every-day affair. A dome of any size is fabricated as easily as our large steel buildings or ships. Its movement on

trucks can be made so smooth that its motion does not disturb the telescope in the least.

If we require special steels or alloys, the assortment we are offered is far larger than we can use. The pyrex glassmaker with his huge tank furnaces stands ready at any moment to let the molten glass flow into the mold, there to cool slowly for months to prevent all strain. Rough-ground and edged, the glass can be raised by means of special lifting apparatus and placed on its bed of counterweighted supports, there to remain until the optician has polished its surface and given it the last touches necessary to converge the star's light into an image smaller in angular size than any ever seen before.

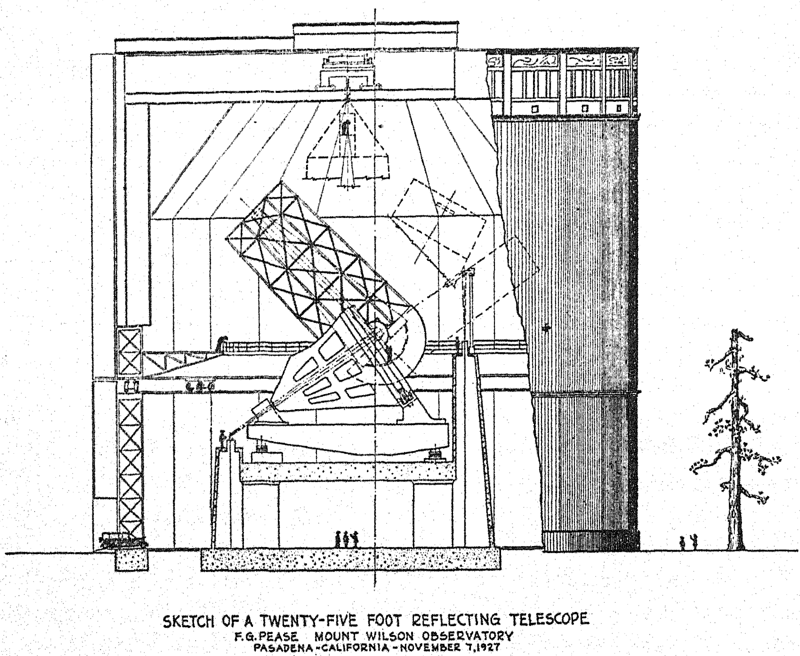


FIGURE 3.—Sketch of 25-foot reflecting telescope

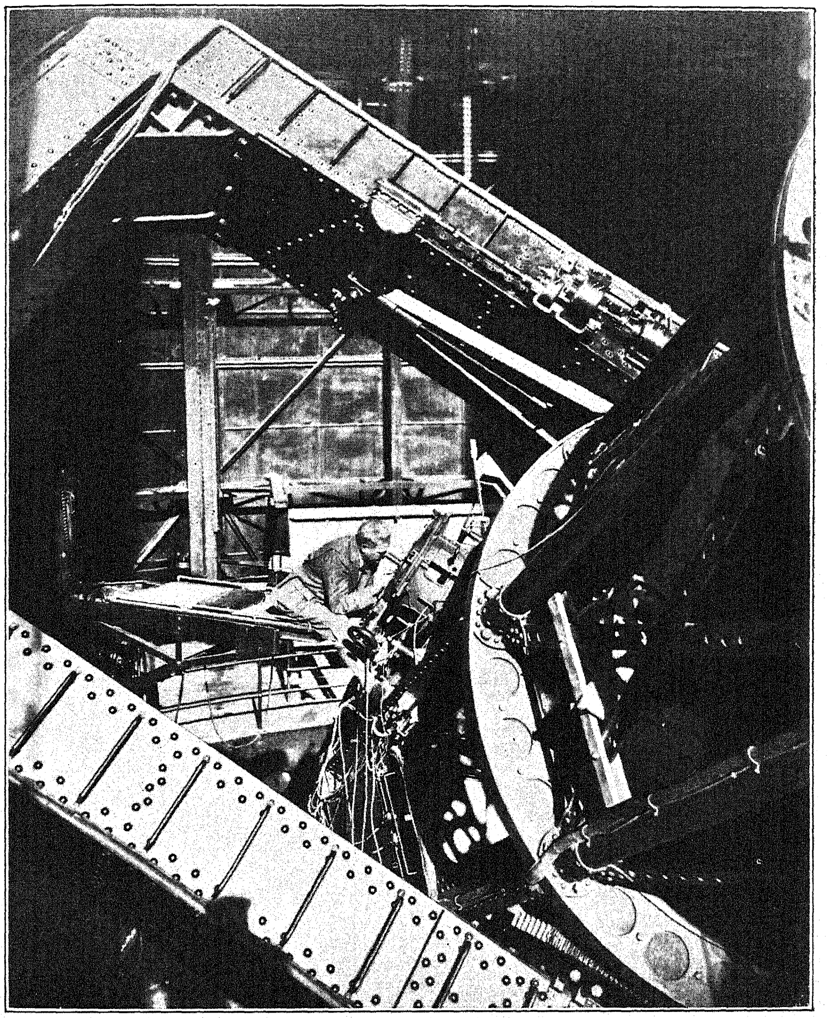
In the August, 1926, number of these Publications[1] was shown a design for a 25-foot reflector planned with a view to making the changes from one attachment to another a matter of only a few moments' time. The observer would stand on a platform just below the opening in the large mirror itself, with practically all of the instruments at hand. The plate holder, spectrographs, photometer, and thermocouple would be mounted each upon a bracket capable of being swung into position with ease. If the night were not good enough for fine nebular photography, five minutes' change would

[1] Publications of the Astronomical Society of the Pacific.

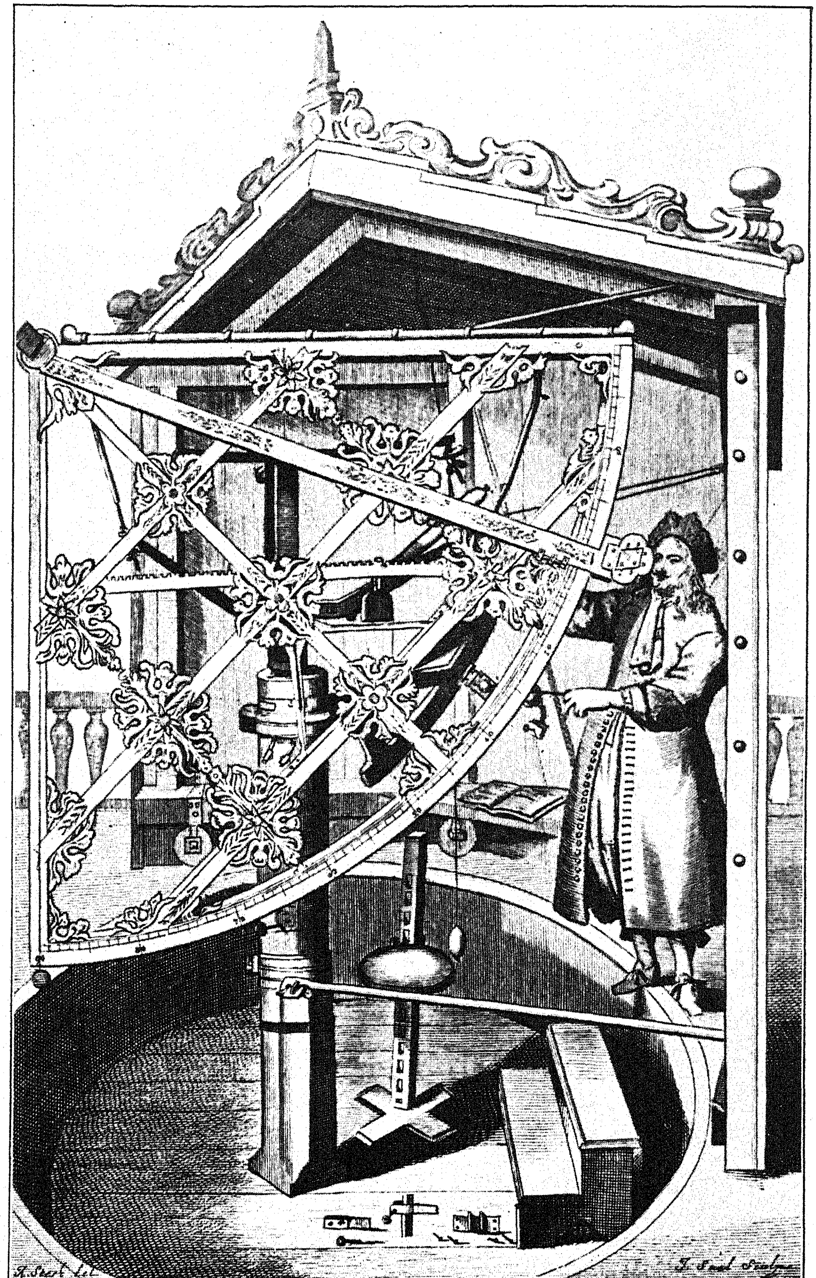
find him at work with the spectrograph or some other instrument which did not require the best seeing.

In Figure 3 is shown an alternative design for a 25-foot reflector which could be used at all the various foci now employed in the 60 and the 100 inch reflectors. The mounting is essentially the same as in the previous design, the principal changes being in the cages and in the dome. The cage shown hanging on the crane is the focal-plane cage. In it the observer would sit, carried along in the telescope, exposing his plates directly in the focus of the large mirror without loss of light by a second reflection, thereby gaining every possible bit of light for the faintest nebulæ and stars. Below the mirror is shown an observer with the instruments best adapted for use at the Cassegrain focus. At either end of the telescope pier there would be a well connected with a constant-temperature room below, which would permit the Coudé focus to be utilized. The rapid change of cages would require a suitable overhead crane. Were we to use such a crane as we now have in the curved dome of the 100-inch Hooker telescope, its weight would have to be counterbalanced and its motion very slow. In a cylindrical dome as shown the crane has a straight travel and a direct hoist, and fast speeds could be used. With a pyrex mirror, easily made to-day, and an invar-steel tube, the images would not only be smaller on account of the larger aperture but they would remain so because the curvature of the mirror would change so little with temperature.

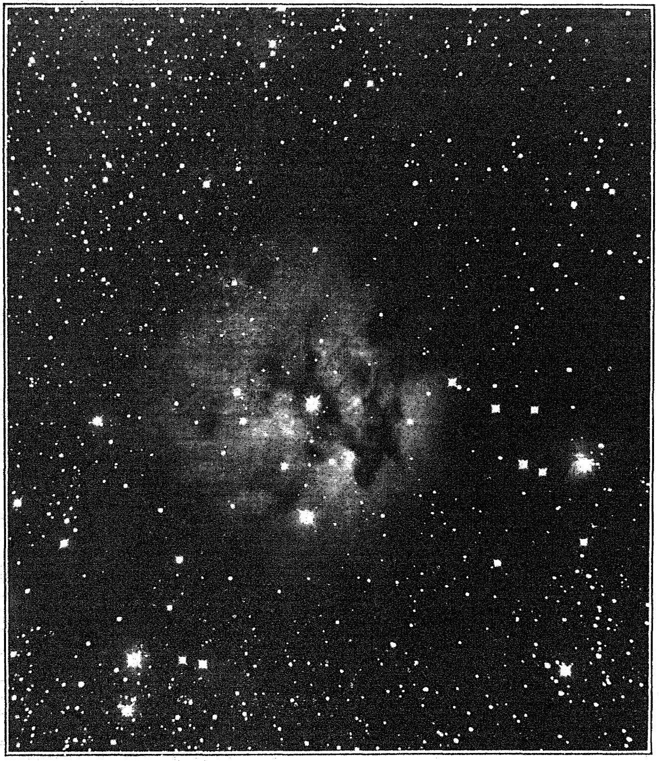
Thus far our great reflectors have been used for observations of planets, stars, and nebulæ, but not of the sun. The domes are double walled to keep out the heat of day; the mirrors are inclosed in insulated walls to prevent more than a degree of change in their temperature. Should we succeed, however, in making a mirror of fused quartz, we could use the telescope for solar work as well. A giant telescope would then yield a double return, because we could utilize its power both day and night.



DOCTOR PEASE OBSERVING WITH THE 100-INCH HOOKER TELESCOPE



ROTATING QUADRANT OF HEVELIUS, MADE BY GÜNTER, 1659

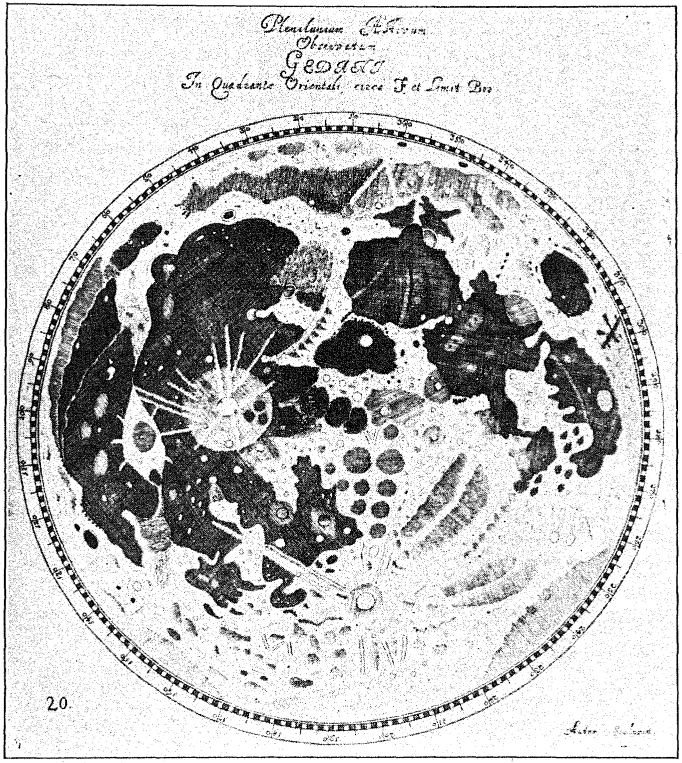


1. PHOTOGRAPH OF IRREGULAR NEBULA IN CYGNUS (G 69, I. C. II 5146), EXPOSURE FIVE HOURS

Made at Mount Wilson Observatory with 60-inch reflector

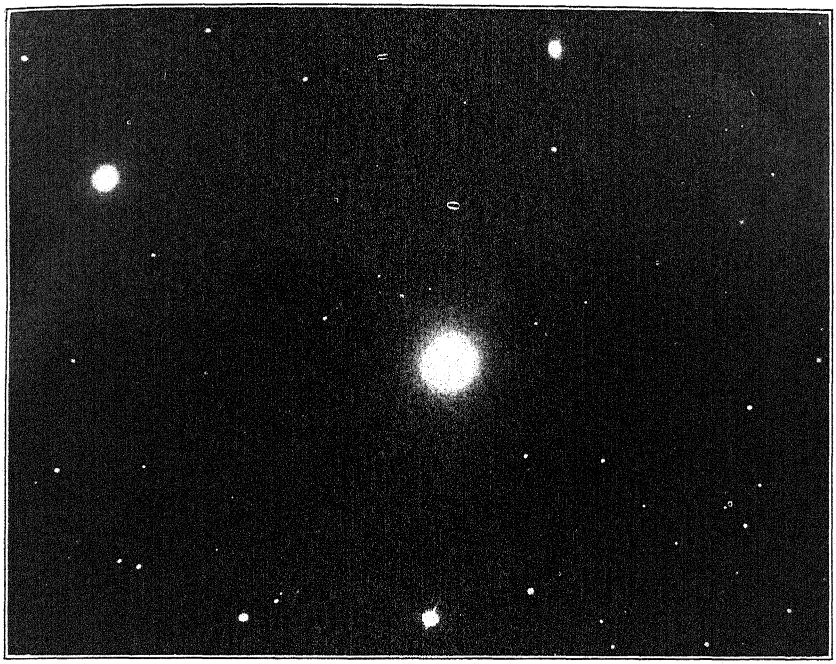
2. PHOTOGRAPH OF REGION IN ANDROMEDA, RESOLVING NEBULOSITY INTO STAR IMAGES (G 122 M 31, N. G. C. 224), EXPOSURE TWO HOURS

Made at Mount Wilson Observatory August 24, 1925, with 100-inch reflector



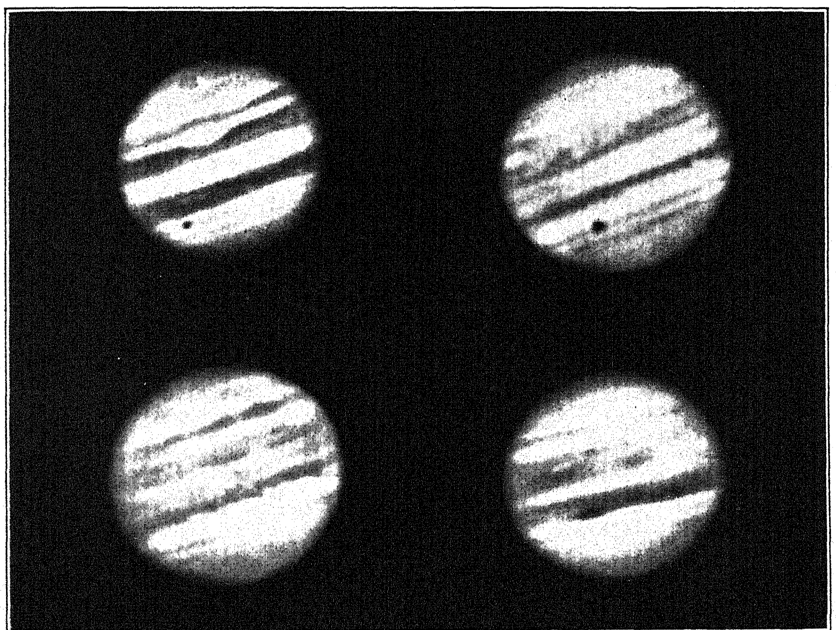
1. DRAWING OF THE FULL MOON BY HEVELIUS

2. PHOTOGRAPH OF THE FULL MOON MADE AT THE LICK OBSERVATORY



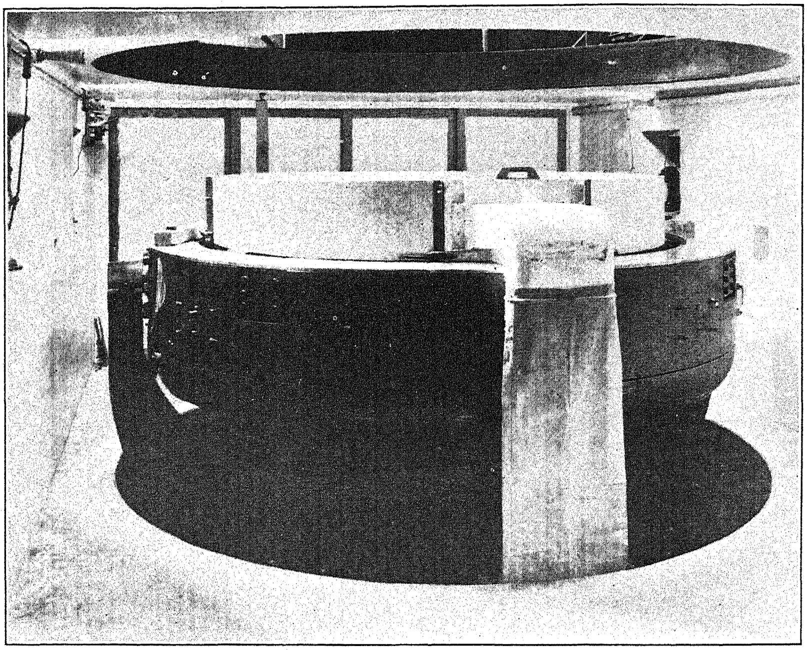
1. PHOTOGRAPH OF GLOBULAR NEBULA OR STAR CLUSTER IN VIRGO (G. 105, M 87, N. G. C. 4486), EXPOSURE TWO HOURS

Made at Mount Wilson Observatory February 26, 1920, with 100-inch reflector

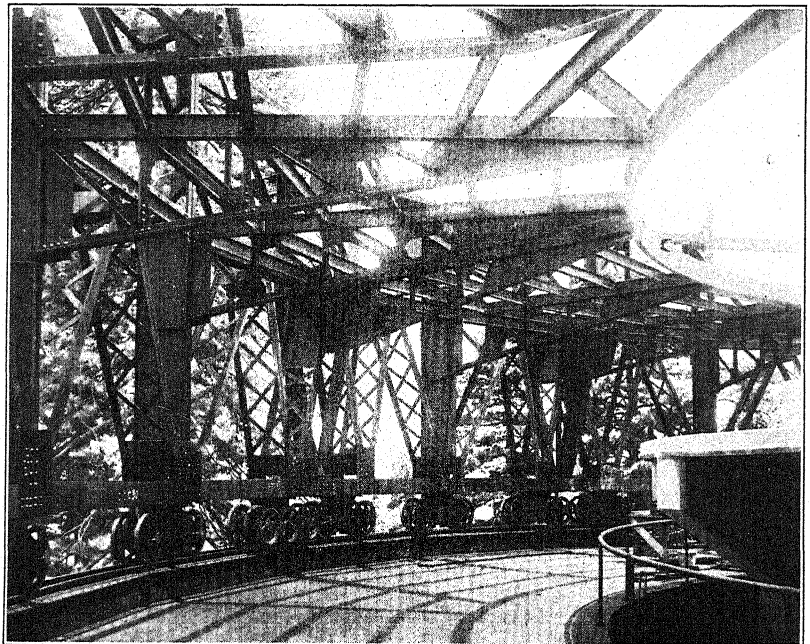


2. PHOTOGRAPH OF JUPITER

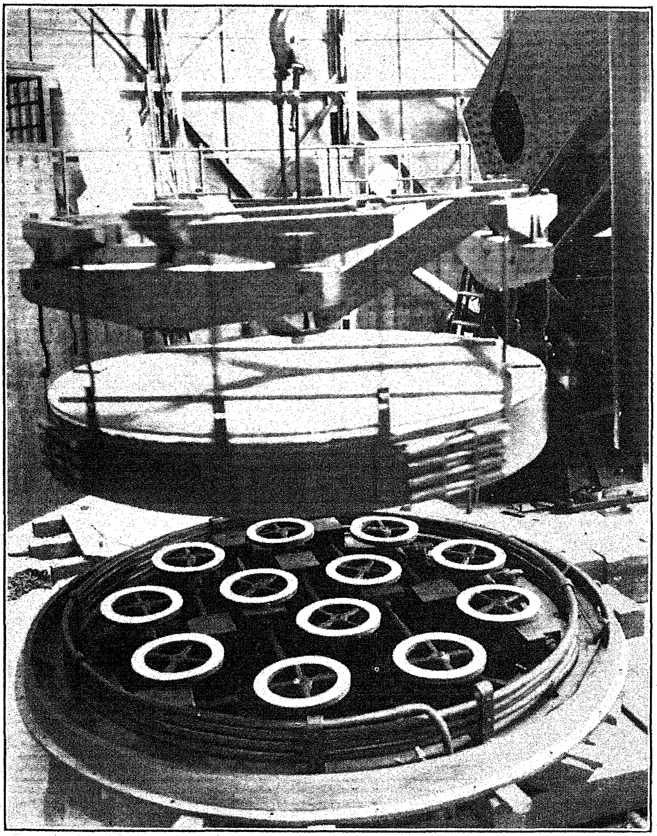
Made at the Mount Wilson Observatory with 100-inch telescope



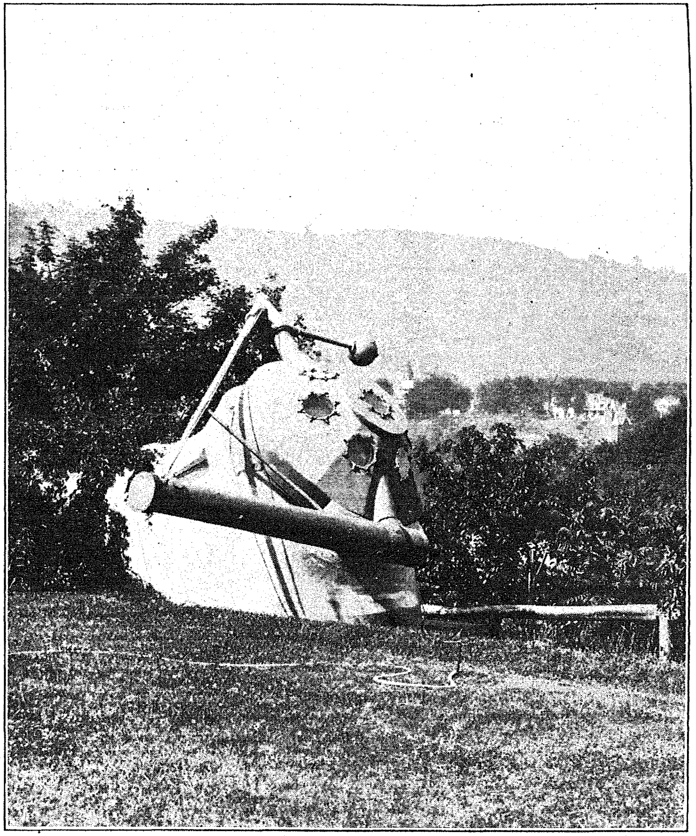
1. THE 100-INCH MIRROR OF THE HOOKER TELESCOPE IN THE SILVERING ROOM WITH SILVERING BAND AND SPOUT ATTACHED, MOUNT WILSON OBSERVATORY



2. RAILS, TRUCKS, AND FRAMEWORK OF BALCONY OF THE DOME FOR HOOKER TELESCOPE, MOUNT WILSON OBSERVATORY



1. LOWERING THE 100-INCH MIRROR OF THE HOOKER TELESCOPE ONTO THE SUPPORTING SYSTEM, MOUNT WILSON OBSERVATORY



2. THE HARTNESS TURRET TELESCOPE

NEW RESULTS ON COSMIC RAYS[1]

By R. A. Millikan and G. H. Cameron

[With one plate]

The cosmic radiation is defined as that small portion of the "penetrating radiation" which is of cosmic origin. The main purpose of this paper is to present a preliminary report upon some very recent work which throws new light upon the properties of these extraordinary rays, and shows that still harder ones exist than had heretofore been found, rays capable of penetrating 190 feet of water, or about 16.7 feet (5 meters) of lead, before being completely absorbed.

Since doubts have been expressed as late as last summer by some of the foremost of living physicists as to whether or not there are any rays which have as yet been definitely proved to be of cosmic origin, and since up to this moment different observers of undoubted credentials, such as Swann,[2] Hoffmann,[3] Kolhörster, and ourselves differ in some cases as much as eight or ten fold in our estimates of the intensity of the cosmic radiation if it exists, our first task will be to present very briefly the nature of the evidence up to the time of these experiments and then to see how the new results supplement this evidence.

This procedure will have the further advantage of presenting a very beautiful illustration of the slow, step-by-step process by which most advances in science are made, each experimenter building on the past, but pushing on, if he is fortunate, a little beyond where his predecessors had gone, until presently the world finds itself in the full glory of a new conception of nature without having been con-

---

[1] This article is made up from several recent papers by the authors; the first part, down to page 222, being the substance of an evening discourse, with additions, delivered by Professor Millikan at Leeds, on Sept. 2, 1927, during the meeting of the British Association, is reprinted by permission from the Supplement to Nature, No. 3036, Jan. 7, 1928.

[2] Swann, Phys. Rev. (29, 372; 1927), finds the ionization due to such rays on the summit of Pikes Peak to be 0.75 per c. c. per sec. per atmosphere, while we found them in the same place to be close to 5 ions.

[3] Hoffmann, Ann. der Physik (82, 413; 1927), finds the ionization at sea level 0.29 per c. c. per sec. on the assumption, taken from Kolhörster's 1926 findings (Zeit. f. Physik, 36, 147; 1926), that the absorption coefficient is invariant and of value $\mu H_2O = 22 \times 10^{-3}$ cm.$^{-1}$. We, on the other hand (Phys. Rev., 28, 851; 1926), found the absorption coefficient definitely variable (the rays therefore inhomogeneous), and the ionization at lea level 1.4 ions.

scious of any particular instant at which the dawn came. Since the days of Greek mythology, very few discoveries have sprung full-grown out of the brain of anyone.

EARLY WORK ON COSMIC RAYS

A starting point in the study of the very "penetrating radiations" near the earth's surface was made in 1903, when these rays were brought to light and named by McLennan,[4] Rutherford,[5] and their collaborators, who found that the rates of discharge of electroscopes could be very markedly reduced by surrounding them with successive screens of lead several centimeters thick, thus showing that rays existed in the atmosphere capable of penetrating such thick screens, and therefore appropriately named the "penetrating radiations."

The next important step was taken by the Swiss physicist Gockel,[6] who in 1910 first took an inclosed electroscope in a balloon to a height of 4,500 meters and found, contrary to expectation, that the radiation was higher at this altitude than at the surface, a fact which at once suggested that all of it, at least, was not of terrestrial origin, but that a part of it came into the earth's atmosphere from above, an idea which had been put forward by O. W. Richardson [7] so early as 1906.

During the next four years, Hess [8] in Austria and then Kolhörster[9] in Germany made other flights like Gockel's, checked his results, and rendered them more quantitative, Kolhörster taking balloon readings up to 9,000 meters and finding the discharge rate decreasing slightly up to about 1,000 meters and then increasing, until at 9,000 meters it was some seven times as great as at the surface—more accurately, 80 ions more than at the surface, since it was this difference which he reported rather than the readings themselves.

The war put a stop for a while to further advances, but in the fall of 1921 and the spring of 1922 Millikan and Bowen [10] took the next important step by building and sending up recording electroscopes in sounding balloons to a height of nearly 10 miles—15,500 meters—more than nine-tenths of the way to the top of our atmosphere, measured by the fraction of the air left below. These flights checked the results of the European observers in indicating an increasing discharge rate up to that height, though the new observed rate was very much less than had been computed from the aforementioned observations up to 9,000 meters; thus showing that the

[4] McLennan and Burton, Phys. Rev., 16, 184; 1903.
[5] Rutherford and Cooke, Phys. Rev., 16, 183; 1903.
[6] Gockel, Phys. Zeit., 11, 280; 1910.
[7] Richardson, Nature, 73, 607; 74, 55; 1906.
[8] Hess, Phys. Zeit., 12, 998; 1911; and 13, 1084; 1912.
[9] Kolhörster, Phys. Zeit., 14, 1153; 1913; and Verh. d. Deut. Phys. Ges., July 30, 1914.
[10] Millikan and Bowen, Phys. Rev., 22, 198; 1923; and 27, 353; 1926.

"penetrating rays," *if they came from above*, were actually more penetrating than had been supposed up to that time. Since if the rays come in from above, the ionization inside airtight electroscopes must increase exponentially—that is, geometrically with the distance of rise toward the top of the atmosphere—these very high flights were, and are now, especially significant. They place very certain and very definite upper limits upon the absorption coefficients of the rays entering the atmosphere, if there are in fact such rays.

The fact, however, that the total discharge of the electroscopes in these flights was but about one-fourth what it should have been from the absorption coefficients, computed on the cosmic ray hypothesis from the data of Hess and of Kolhörster, suggested some other cause for the phenomenon. For up to this time the increasing rate of discharge with altitude was the chief if not the sole phenomenon upon which the hypothesis of rays of cosmic origin rested. But other alternatives were possible and had indeed been suggested; such, for example, as radioactive particles of unknown origin spread through the upper regions of the atmosphere. Such an alternative could be tested definitely by making direct measurements of the coefficients of absorption of the penetrating rays rather than attempting to compute these coefficients as had heretofore been done, on the assumption that the rays entered the atmosphere from above. For if the rays were of radioactive origin, they would not be expected to be appreciably harder than those of the known radioactive substances such as thorium D or radium C.

The next step was taken during summer of 1923, when Kolhörster [11] in Europe and Millikan and Otis [12] in America independently made the first direct absorption measurements with materials other than the atmosphere itself—the former in Alpine glaciers and in shallow bodies of water at sea level, the latter in thick lead screens carried to the top of Pikes Peak—for the sake of throwing new light on the possible origin of the penetrating rays.

Kolhörster reported as a result of his glacier experiments an absorption coefficient of 0.25 per meter of water, or about half that previously found, namely, 0.55, thus eliminating the discrepancy between the findings from his balloon flights and our sounding balloon experiments. He states in the paper describing this work that his experiments prove definitely the existence of gamma rays of about one-tenth the absorption coefficient of the hardest known gamma rays (4.1 per meter of water),[13] but speaks with reserve about their origin. He says, after discussing various alternatives, that "one inclines more and more of late to the view that the penetrating

---

[11] Kolhörster, Sitz. Ber. d. Preuss. Akad., 34, 366, Dec. 20, 1923.
[12] Millikan and Otis, Phys. Rev., 23, 778; April, 1924. Also 28, 851; 1926.
[13] Radioactivity, Bull. Nat. Res. Council, Kovarik and McKeehan, p. 114, 1925.

rays are a phenomenon the origin of which is to be sought in the cosmos."[14]

Millikan and Otis, on the other hand, concluded from their new Pikes Peak absorption data that if any of the penetrating rays which they found on the Peak were of cosmic origin they had to be more penetrating, or less strong, than corresponded even with the reduced values now found by Kolhörster, namely, 2 ions at sea level, absorption coefficient 0.25 per meter of water. The mean coefficient of the radiation which they found on Pikes Peak was but slightly less than that of thorium D, and a large part of it was certainly of local origin. They brought to light in these experiments no new evidence for the existence of rays of cosmic origin. Indeed, up to 1925, there appears from the literature to have been no feeling of certainty in any quarter that the existence of rays of cosmic origin had been proved. The increase in ionization in closed vessels up to nearly 10 miles was an undoubted fact, and Kolhörster's glacier experiments were favorable to the cosmic ray interpretation; but the possibilities of the radioactive contamination of a glacier are not small, nor do its irregular shape and proximity to land masses adapt it well to trustworthy absorption-coefficient measurements. Further, Hoffmann,[15] in Germany, with an extraordinarily fine technique, had in 1925 pronounced against the existence of rays of cosmic origin. Also in America, Swann[16] was convinced that the work of himself and his collaborators with the ionization in vessels at pressures up to 75 atmospheres was incompatible with the cosmic ray interpretation of the penetrating radiation.

OBSERVATIONS IN MOUNTAIN LAKES

In 1925, however, Millikan and Cameron got unambiguous evidence from their own point of view of a penetrating radiation which had to be of cosmic origin. It was indeed weaker and more penetrating than had corresponded to preceding estimates, having an ionizing power at sea level of but 1.4 ions per cubic centimeter per second, an absorption coefficient which became as small as 0.18 per meter of water, and a definite spectral distribution, the longest wave lengths found having a value, computed from A. H. Compton's formula, $\lambda=0.00063$ A, the shortest 0.00038 A. This last is but one-thirtieth the wave length of the very hardest gamma rays.

---

[14] "Neuerdings neigt man immer mehr der Ansicht zu die Höhenstrahlung als eine Erscheinung aufzufassen, deren Ursprung im Kosmos zu suchen ist." Again: "Da für die erstere Auffassung der Höhenstrahlung als einer aus den höheren Atmosphärenschichten stammenden bisher keinerlei direkta Andeutung gefunden wurde, so sprechen die augenblicklichen Verhältnisse mehr zugunsten einer kosmischen Erklärung."

[15] Hoffmann, Phys. Zeit., 26, 40, 669; 1925.

[16] Downey, Phys. Rev., 20, 186; 1922. Fruth, Phys. Rev., 22, 109; 1923.

These experiments consisted in sinking sealed electroscopes in deep, high-altitude, snow-fed lakes, and thus finding, to take a particular case, that the ionization in Muir Lake (altitude 11,800 feet or 3,590 meters) decreased steadily with depth from 13.3 ions per cubic centimeter per second at the surface to 3.6 ions at 60 feet (18 meters) below the surface, below which point there was no further measureable decrease with instruments of such sensibility as were being used. *This was the first time the zero of an electroscope—the reading with all external radiations, both local and cosmic, completely cut out—had been definitely determined, and the results accordingly began to show that it was possible to make with certainty determinations of the absolute amount of the penetrating radiation.*

Up to the point to which we have thus far described the experiment, it proved merely either the existence at the surface of the lake of a penetrating radiation so hard as to be able to penetrate 60 feet (18 meters) of water before becoming completely absorbed, or else a very strange distribution of radioactivity in the water of the lake. We therefore tested the radioactivity of the water and found it immeasurably small, not one-hundredth part of the activity of ordinary tap water in Pasadena.

Next, by taking similar readings in another deep, snow-fed lake, 300 miles farther south and having an altitude 6,700 feet (2,060 meters) lower, *we found a similar curve, but with each reading displaced just 6 feet upward.* But 6 feet of water was exactly the equivalent in absorbing power, where the mass absorption law holds, of the layer of atmosphere lying between the altitudes 11,800 feet (3,590 meters) and 5,100 feet (1,530 meters).

These experiments, supplemented by later similar findings in other lakes, therefore proved definitely three things:

First, that the effects in Muir Lake had not been due to any radioactivity which happened to be distributed in the water in a particular way.

Second, that the source of the rays was not at all in the layer of atmosphere between the two altitudes, for this layer acted in every particular like an absorbing blanket, having precisely the absorption that it should have *if the rays came in wholly from above.*

Third, that in different localities 300 miles apart, north and south, the rays were *exactly* alike at the same altitudes.

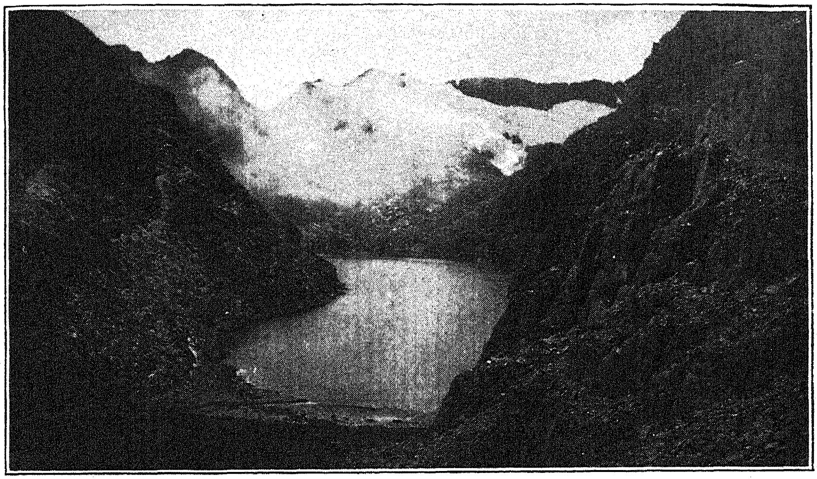
These facts, combined with the further observation made both before by Hess (loc. cit.) and others and at this time by ourselves, that within the limits of our observational error the rays came in equally from all directions of the sky, and supplemented finally by the facts that the observed absorption coefficient and total cosmic ray ionization at the altitude of Muir Lake predict satisfactorily the results obtained in the 15.5-kilometer bal-

loon flight—*all this constitutes pretty unambiguous evidence that the high-altitude rays do not originate in our atmosphere, very certainly not in the lower nine-tenths of it, and justifies the designation "cosmic rays,"* the most descriptive and the most appropriate name yet suggested for that portion of the penetrating rays which come in from above. We shall discuss just how unambiguous the evidence is at this moment after having presented our new results.

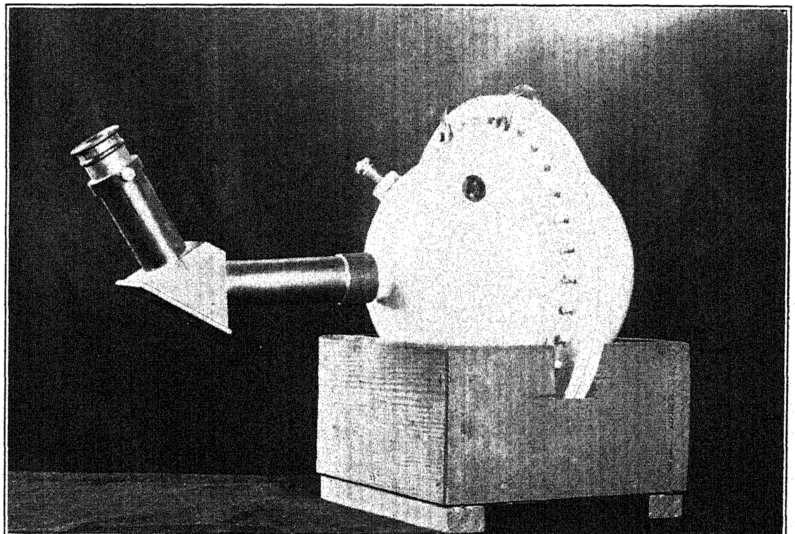
These represent two groups of experiments, one carried out in Bolivia in the high Andes at altitudes up to 15,400 feet (4,620 meters) in the fall of 1926, and the other in Arrowhead Lake and Gem Lake, Calif., in the summer of 1927.

PENETRATING RADIATION IN THE HIGH ANDES

The experiments in the high Andes had four prime objectives as follows: (1) To see whether in lakes in the Southern Hemisphere the altitude-ionization curve would coincide with that found in lakes in the Northern Hemisphere. This curve was particularly sensitive in the very high altitude lakes obtainable in the high Andes, and the spectral distribution found in 1925 could be more accurately tested. If the Northern Hemisphere and the Southern Hemisphere curves coincided, it would go a long way toward eliminating the possibility that the rays are generated by the incidence of high-speed beta rays on the very outer layers of our atmospheres—about the only hypothesis which could put the source of these rays in the last tenth of the air about the earth. For such beta rays would be expected to be influenced by the earth's magnetic field so as to generate stronger radiation over the poles than over the Equator. In latitude 17° S. we should be completely screened from such pole effects, particularly if we could get into suitable high-altitude pockets in the mountains. (2) To obtain further crucial tests of the C. T. R. Wilson hypothesis that these rays may be due to the integration of the effects of the impact in the earth's atmosphere of electrons endowed with many millions of volts of energy acquired in thunderstorms. Lakes in suitable pockets in the high Andes would be completely screened from such effects. Also, a comparison of the rays found in thunderstorm areas with those found in large regions like California which are comparatively free from thunderstorms might furnish check observations upon this point. (3) By determining, as outlined above, the zero readings of new electroscopes to obtain new checks on our value of the ionization due to the cosmic rays at sea level, a quantity upon which as yet there have been wide divergences between the results of different experimenters. (4) To get into suitable pockets or valleys in very high mountains where the rays are three or four times as intense as at sea level, and there to make more trustworthy tests on directional effects in cosmic rays—in particular



1. LAKE MIGUILLA, BOLIVIA. ALTITUDE, 15,000 FEET (4,500 METERS), ABOUT 2,000 FEET LONG, 700 FEET WIDE, AND 175 FEET DEEP



2. THE TYPE OF ELECTROSCOPE SUNK TO DEPTHS OF 200 FEET BEFORE ITS READINGS BECAME CONSTANT AT 2.4 IONS/C.C./SEC. READINGS AT SURFACE, 33.6 IONS/C.C./SEC.

to see whether the Milky Way is more or less effective than other portions of the sky in sending these rays into the earth.

On all these four points we obtained, despite unfortunate accidents with two of the electroscopes, satisfactory and definite information.

As to (1), we obtained on the surface of Lake Titicaca (altitude 12,540 feet or 3,822 meters) readings which corresponded very nicely with similar ones taken at Muir Lake, Calif. Also, in Lake Miguilla, near Caracoles, Bolivia (altitude 15,000 feet or 4,500 meters), we obtained readings which fell satisfactorily on the extrapolated Muir Lake curve. If, then, there are any geographical differences in the altitude-ionization curve, they are beyond the limits of our present observational technique.

As to (2), Lake Miguilla is a small lake surrounded on all sides by mountains several thousand feet high. It would be completely shielded from rays having their origins in thunderstorms anywhere on the earth. Further, off the coast of Central America we took a long series of readings in the wireless room on shipboard on a night on which a brilliant display of lightning was going on along the coast, and we compared the results with readings taken on the California coast, which is almost entirely free from thunderstorms, without bringing to light the slightest difference. The C. T. R. Wilson hypothesis is therefore quite definitely eliminated.

As to (3), we took the zeros of two of our electroscopes by sinking them to sufficient depths and then made an elaborate series of sea-level observations on the ship all the way from Mollendo, Peru, to Los Angeles. *We found no variation in sea-level reading with geographical position*, and but slight differences between the ionizations in different instruments, though they had volumes nearly in the ratio 1 to 2 and different sorts of walls. The mean value of the sea-level ionization thus directly observed was but a few tenths of an ion above the mean of the sea level cosmic ray ionizations given by the two curves of our preceding report. These curve-values were 1.4 for electroscope No. 1, and 1.6 for electroscope No. 3—mean value 1.5, which is thus checked approximately, though not yet accurately (see below), since the ionization due to the radioactive matter in the air above the ocean must be very small. The main uncertainty in this present value 1.5 for the sea-level ionization lies in the determination of the capacities of the electroscopes, and in uncertainties in the effect of electroscope walls. Upon the latter effect we shall make a later report.

As to (4), we took two long series of observations, each lasting 3 days, at an altitude of 15,400 feet (4,620 meters) in a deep valley from which the Milky Way was in sight for a period of 5 or 6 hours and then practically out of sight for another 6 hours. The value of the cosmic rays which entered our electroscopes in this valley

was 3.6. *We could detect no difference at all in the value of the readings when the Milky Way was overhead and when it was out of sight.* Our error in the mean values of these readings could scarcely be more than 0.1 ion. Even if we double this estimate so as to have a wide factor of safety, we may conclude at least that the Milky Way exerts no influence upon the cosmic rays which it is yet within the power of the instruments used to detect, and that this should mean that the rays coming from the direction of the Milky Way are not 6 per cent greater or less than are those coming from the portion of the heavens at right angles to the Milky Way. This is in agreement with our preceding less discriminating measurements, and also with recent very careful work at sea level by Hoffmann and Steinke,[17] who can find there no directional effect in cosmic rays at all; but it is at variance with results reported by Büttner[18] and by Kolhörster.[19]

This present work was, however, done under quite as favorable conditions as have ever been used. It is very important to obtain unambiguous evidence upon this point. No entirely trustworthy conclusions about the origin of the rays can be drawn until it is settled. As yet, the case for a favored region from which the rays come does not seem to have been established, but more sensitive tests can be made and will be made in the near future.

OBSERVATIONS IN CALIFORNIAN MOUNTAIN LAKES

The object of the new group of experiments at Arrowhead and Gem Lakes, begun early in 1927, was to use an increased electroscope sensibility and an increased accuracy in the determination of the electroscope constants, for the sake of introducing greater precision into cosmic ray determinations and placing the whole subject upon a more strictly quantitative basis.

As already indicated, different observers are still wide apart on the absolute value of the ionization, though a considerable group of us now find it to be between one and two ions at sea level. This, however, can scarcely be called quantitative agreement. But this could scarcely be expected, since no observers except ourselves have thus far been able to determine the zeros of their instruments; so that most reported values of ionizations must be regarded as estimates rather than measurements. Our own values suffer from rather large uncertainties in the determination of the capacities of our electroscopes.

As to mean absorption coefficients, Kolhörster and ourselves are now in reasonable agreement, but no one except ourselves had until

---

[17] Steinke, Zeit. f. Phys., 42, 570; 1927.
[18] Büttner, Zeit. f. Geophys., 2, 190; 1926.
[19] Kolhörster, Naturwissenschaften, 14, 936; 1926.

very recently brought to light the inhomogeneity of the rays though the latest results by Hoffmann and Steinke lead them to support provisionally our findings and to suggest that in the mixture of cosmic rays some may exist even harder than the hardest brought to light by us. These we found to have an absorption coefficient equal to 0.18 per meter of water, which corresponds, if computed by Compton's equations, to a wave length 0.00038 A, or an equivalent generating potential of 32,600,000 volts. Hoffmann,[20] in order to explain his latest sea-level readings, assumes components of hardness corresponding to a wave length, computed in the same way, of 0.00029 A, or an equivalent generating potential of 41,000,000 volts.

We began in the fall of 1926 to build new electroscopes of greater sensibility to the cosmic rays in the hope of determining the intensities of these rays more precisely and studying their spectral distribution more discriminatingly; in particular, we wished to test for the presence of still harder rays than could be brought to light by the sensibility of our preceding instruments; for there were theoretical reasons for suspecting that still harder rays might exist. These electroscopes will be described in detail in more technical papers. Suffice it to say here that we can now measure the capacities of electroscopes to a few parts in a thousand (0.791 electrostatic unit is the capacity of the instrument with which the following results have been obtained), and that we are now using from eight to fifteen times the sensibility to cosmic rays that we have heretofore employed; so that at sea level we have in our electroscope say 27 cosmic ray ions to play with instead of about 2, and at Pikes Peak about 90 instead of 5 or 6.

In carrying out experiments with this electroscope in Gem Lake in the summer of 1927, the ionization at the surface of the lake was 33.6 per cubic centimeter per second, and it decreased with depth of immersion, *regularly and very smoothly, to a zero value of 2.4. But this asymptotic value of the ionization-depth curve was only reached at a depth of 164 feet (50 meters)* instead of at about 54 feet (16.2 meters) as in our preceding 1925 Arrowhead experiments. This does not represent a discrepancy between the two sets of results. It means only that the ionization ordinates of the curve have now been multiplied manyfold by the increased sensibility. In spite of this, the series of ionization-depth readings taken with the new electroscope falls much more smoothly upon the curve, that is, shows less scattering, than was the case before; so that by improvements in technique the actual sensibility has been multiplied considerably more than eightfold. It is this increased sensibility and precision of measurement alone which is responsible for the fact that at depths

[20] Hoffmann, Ann. der Phys., 82, 417; 1927.

between 54 feet and 164 feet ionization is now clearly shown which was before masked by observational uncertainties.

Taking into account the absorption of the atmosphere above Gem Lake, which is the equivalent of 7.45 meters of water, *the new experiments reveal rays so penetrating as to pass through 60 meters (200 feet) of water, or 18 feet of lead before being completely absorbed.*

The new curve can be analyzed for spectral distribution much more reliably than has been heretofore the case; but it is very satisfying that, analyzed by the method before used, the portion in the neighborhood of the elevation of Arrowhead yields precisely the same coefficient as did the former curve in the same region, namely, 0.22 per meter of water, while *the lowest part of the curve yields the coefficient 0.04 per meter of water, so that we have here brought to light rays nearly five times as penetrating as those heretofore found by us.* Computed as below, the shortest wave length is now 0.000058 A, the equivalent generating potential of which is 216,000,000 volts, very much higher than the estimates made by Hoffmann.

Our total curve now extends from an absorption coefficient of $\mu = 0.22$ per meter of water to $\mu = 0.04$, or in equivalent wave lengths computed as below 0.0005 A to 0.00006 A, *a range of three octaves.*

EVIDENCE FOR THE CONTINUOUS CREATION OF THE COMMON ELEMENTS OUT OF POSITIVE AND NEGATIVE ELECTRONS

What can now be said with reference to the possible source of these extraordinary rays? Their penetrating power alone—or frequency, computed by whatever formula—obviously requires that they correspond to changes of some sort taking place within the nucleus itself, since no extra nuclear charges can possibly be associated with anything like such energies.

The evidence is now strong that they are due to the continuous creation *at the present time* of the more stable and more abundant elements like helium (abundant in the heavens), oxygen, silicon, and iron, out of the primordial positive and negative electrons, the former of which is the nucleus of the hydrogen atom. This evidence may be summarized at follows:

First.—The pilot-balloon experiments of Millikan and Bowen,[10] in which they sent up recording electroscopes 0.92 of the way to the top of the atmosphere and in which the absorption coefficient of the cosmic rays at, or near, the top of the atmosphere came out of the same order of magnitude as that found near the sea level,[21] show conclusively that these rays consist of a definite and distinct region of spectral frequencies, or oscillations, a hundred times more rapid than those produced by the most powerful subatomic changes here-

[10] Millikan and Bowen, Phys. Rev., 22, 198; 1923; and 27, 353; 1926.
[21] Millikan and Cameron, ibid. 31, 163 (1928).

tofore known, namely, those accompanying radioactive processes. Otherwise stated, these experiments show conclusively that there are no radiations of appreciable intensity entering the earth's atmosphere having frequencies intermediate between those of the gamma rays and those of the cosmic rays. For, since the hardest gamma rays are capable of penetrating a thickness of about 70 centimeters of water, while, as indicated below, the cosmic rays are capable of penetrating 70 meters of water, and since penetrating power increases approximately as frequency, if rays of appreciable intensity came into the atmosphere having frequencies between those of gamma rays and those of the cosmic rays, they would of necessity have caused the rapid discharge of an electroscope which rose to within the equivalent of 80 centimeters of water of the top of the atmosphere, the whole of the earth's atmosphere being the equivalent of 10 meters of water. No such rapid discharge took place; hence there are no strong radiations entering the earth's atmosphere in that particular region of frequencies.

Second.—The experiments of Millikan and Cameron of the summer and fall of 1927 made in deep, high-altitude California lakes with new electroscopes eight times more sensitive than those the authors had theretofore used, brought to light the definite proof that the cosmic-ray spectrum consists of definite bands, like those of neon or mercury lamps, containing spectral lines as much as three octaves apart, the highest frequency band having so enormous a penetrating power that it passes through as much as 200 feet of water (18 feet of lead) before becoming completely absorbed. This discovery of a banded structure in the cosmic rays shows that they are not produced as are X rays by the impact upon the atoms of matter of electrons which have acquired large velocities by falling through powerful electrical fields, as we had earlier suggested; but that *they are rather produced by definite and continually recurring atomic transformations involving very much greater energy changes than any occurring in radioactive processes.* The proof of the banded structure of the cosmic-ray spectrum is found in the fact that the new ionization-depth curve (fig. 1), which is seen to be of very much higher resolving power than any heretofore obtained, when taken in connection with the sounding balloon data, shows a nearly constant absorption coefficient from close to the top of the atmosphere down to about sea level, 10 meters below the top, then bends quite suddenly and uncovers below 15 meters a new absorption coefficient of only about one-sixth the former value, which continues down to 70 meters below the top with but little further change. The cosmic rays therefore consist of at least two, possibly more (see below), radiation bands of absorption coefficients (and therefore, roughly, also of frequencies) in the ratio of 8 to 1. The sharpness

of the bend in the ionization-depth curve is completely incompatible with any general distribution of the frequencies of cosmic rays like that found in white light, or in the general X radiation which is produced by the bombardment of the atoms of a target by high-speed electrons (cathode rays).

Third.—If the Einstein special theory of relativity may be taken as a sound basis of reasoning—and no results predicted by it have ever thus far been shown to be incorrect, while it has many striking successes to its credit—then it follows that radiant energy can never escape from an atomic system without the disappearance of an equivalent amount of mass from that system, these relations being contained in the now well-known and universally used equation of

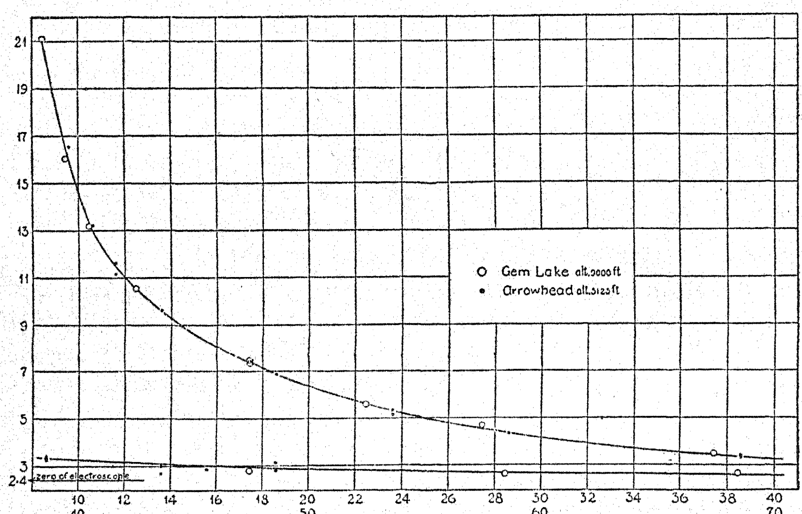


FIGURE 1.—Ionization in cc./sec. against depth in equivalent meters of water beneath top of atmosphere; upper curve 8 to 40 meters, lower 38 to 70 meters

Einstein (1905) $Mc^2 = E$, where M is mass in grams, c is the velocity of light in centimeters per second and E is energy in ergs. Now through the recent, very exact work of Aston [22] we know the mass of every one of the atoms with a great deal of certainty, and we can therefore compute the amount of ether-wave energy that can be generated by any sort of atomic transformation that can take place, and knowing this energy we can compute with the aid of the Einstein equation the frequency, and with the aid of the Dirac formula [23] the penetrating powers of the rays resulting from all possible atomic transformations. *Such studies reveal the fact that there are no possible transformations capable of yielding rays of the enormous penetrating power observed by Millikan and Cameron except those cor-*

[22] Aston, Proc. Roy. Soc., 115, 487 (1927).
[23] Dirac, ibid., 109, 206 (1925).

responding to the building up or creation of the abundant elements like helium, oxygen, silicon, and iron out of hydrogen, or in the case of the last two elements out of helium. The entire annihilation of hydrogen by the falling completely together of its positive and negative electrons might be an additional possibility, but it can be eliminated in this case for two excellent reasons. The first of these reasons is that there is practically no place whatever for such a radiation to occupy in the observed ionization-depth curve (see fig. 1), for it would be between four and five times more penetrating than the radiation that has the smallest absorption coefficient mentioned above. The ionization due to it, if it exists, would then have to be included in the 2.4 ions, which represent the "zero of the electroscope" as shown in the figure. But this 2.4 ions is only about one-tenth of the observed ionization at the top of the curve, viz, 21 ions, this topmost reading corresponding to a depth of 1 meter below the surface of Gem Lake. So that this hypothetical radiation can have nothing to do with the observed ionization-depth curve much above the reading 2.4, and below it there is, of course, room only for a radiation relatively negligible in intensity in comparison with the softer rays that are responsible for the observed curve. The second reason is that this hypothetical radiation, if it were present, would of necessity be homogeneous, and could not therefore exhibit the banded structure shown by the observed cosmic rays. Whether then this act of the entire annihilation of the hydrogen atom through the coming into complete coincidence of the positive and negative electrons takes place or not, it can certainly be eliminated as a cause of the *observed* cosmic rays. There remains, then, no other atomic transformation in which sufficient mass disappears to create the observed cosmic rays except the aforementioned atom-building processes. It is important to note that no step-by-step process of building up, or for that matter of disintegrating, of atoms in which one positive electron or one alpha particle is added or subtracted at a time will suffice for the generation of the cosmic rays, since the Einstein equation tells us that in no case can such a transformation produce rays of more than from one-fourth to one twenty-fifth of the observed penetrating power. The observed extraordinarily penetrating cosmic rays present, then, when taken in connection with Einstein's equation and Aston's findings, not only the first direct evidence that the more abundant elements are now in process of being created out of positive and negative electrons but they also present the first indications as to the general character of the specific act or acts by which the atom-building process goes on. So far we have used only the general or qualitative evidence, but it will be seen that from it alone the conclusion is scarcely escapable that the powerful cosmic rays here studied can be produced only by the creation in a single act, rather than by a step-by-step

process, of some, at least, of the common elements out of the primordial positive and negative electrons.

Fourth.—The evidence herewith obtained is, however, not merely qualitative but, if Dirac's formula is dependable, fairly accurately quantitative. For we analyzed very carefully our cosmic-ray curve empirically before we called on any theoretical considerations whatever to explain it, and we reported in scientific papers that our observed curve demanded three cosmic-ray bands of absorption coëfficients 0.35, 0.08, and 0.04 per meter of water, respectively. It was after this work had been done, reported in seminars, written up, and prepared for publication in essentially the form in which it has appeared[24] that we set about computing from the foregoing considerations what the theoretical absorption coefficients would be if our observed cosmic rays were produced (1) by the formation in one single act of helium out of hydrogen, (2) by the similar formation of oxygen out of hydrogen, and (3) by the formation of silicon out of hydrogen. The results of this computation with the aid of Dirac's formula came out 0.30, 0.075, and 0.043, well within the limits of the resolving power of our curve of the observed values. Further, there are only a few elements so abundant that their formation needs to be considered as the possible source of the observed cosmic rays. For the spectroscopy of the heavens shows a very great abundance everywhere of the gases hydrogen, helium, and nebulium. But Bowen[25] has just identified the last as nitrogen and oxygen so that these gaseous elements, hydrogen, helium, nitrogen, and oxygen seem to be extraordinarily widely spread through space. As to the elements found in solids the meteorites have 96 per cent of their mass in the four elements, oxygen, magnesium, silicon, and iron. Magnesium and silicon are close together in atomic weight, 24 and 28, respectively, so that their formation would constitute but one band, the mean energy of which lies approximately at $\mu=0.04$. It was this joint band that we above called for convenience the silicon band. Similarly the atomic weights of nitrogen and oxygen are respectively 14 and 16, and the mean absorption coefficient 0.08 corresponds to this joint band. The helium band, most significant of all, corresponds to $\mu=0.30$. There is no other abundant element except iron, and the formation of this out of hydrogen gives a cosmic ray for which $\mu=0.021$. The existence of such a radiation helps rather than interferes with the fit of our theoretical and experimental curves, but on account of the lack of resolving power in the lower end of our curve it furnishes no trustworthy evidence that this particular act is the one by which iron is most commonly formed. This uncertainty

[24] Millikan and Cameron. Phys. Rev., June, 1928.
[25] Bowen, Astrophys, Jour. 57, 1, 1928.

does not exist, however, with respect to the bands corresponding to $\mu=0.30$, $\mu=0.08$, and $\mu=0.04$. *This whole work constitutes, then, very powerful evidence that the sort of creative, or atom-building processes discussed above, are continually going on all about us, probably not at all in the stars* (*see below*), *and that each such event is broadcast through the heavens in the form of the appropriate cosmic ray.*

EVIDENCE THAT THE COSMIC RAYS ORIGINATE IN INTERSTELLAR SPACE

If it may be regarded as established by the evidence thus far advanced that the cosmic rays are the signals sent out through the heavens of the creation of the common elements out of positive and negative electrons, the next important question to attempt to answer is "where are these creative processes going on"? To this question there are just two possible answers, as follows:

(1) In the stars where pressures, densities, and temperatures may, one or all, be enormously high; or else,

(2) in interstellar space where pressures, densities, and temperatures are all extraordinarily low.

In both of these localities matter exists under extreme and as yet unexplored conditions, and in view of the history of the last 30 years of physics, it would no longer be surprising if matter were again found to behave in some hitherto unknown and unexpected way as a new field of experimentation is entered.

Of the two foregoing alternatives we think it possible to eliminate the first and to establish the second with considerable definiteness, and that for the two following reasons:

First. If the mere presence of matter in large quantities and at high temperatures favored in any way the atom-building processes which give rise to the cosmic rays, then it is obviously to be expected that the sun, in view of its closeness, would send to the earth enormously more of them than could any other star. But the fact is that all observers are agreed that the change from midday to midnight does not influence at all the intensity of the cosmic rays.

Since, however, the rays do come to us at all times, day and night, and, according to all observers, at least, very nearly equally from all directions, there is scarcely any escape from the conclusion that *the atom-building processes giving rise to the cosmic rays are favored by the conditions existing in interstellar space.* If then, in going from a point in interstellar space toward the center of a star the favorable conditions for atom-building existing in outer space have disappeared as the surface of the star is reached it is well-nigh inconceivable that they will again reappear in penetrating from the surface to the center—a path along which the changes in physical

conditions all continue unchanged in direction. So that from the foregoing we may not only conclude quite definitely that the stars are not the sources of the observed cosmic rays, but also that the main *atom-building processes probably do not take place inside of stars at all.*

Second. The foregoing conclusions may also be arrived at from an entirely different mode of approach, namely, from our measurements upon the absorption coefficients and the total energy content of the cosmic rays.

The hardest rays which we have observed are completely absorbed (reduced to say 2 per cent of their initial intensity) in going through 70 meters of water. This means that even if the atom-building processes went on inside a star, the resulting cosmic radiations could not possibly get out, but would all be frittered away in heat [26] before emergence, save in the case of those rays that originated in the star's very outermost skin—a skin equivalent in absorbing power to a hundred or so meters of water.[27]

But we have also found that the total energy coming into the earth's atmosphere in the form of cosmic rays is about one-tenth the total heat and light energy coming to the earth from the stars exclusive of the sun. This last fact means that *if the cosmic rays have their origins within the stars they can not even at the points of their origin have an intensity more than 10 times that which they have when they reach the earth's atmosphere, for if they had then the cosmic-ray energy transformed into heat by absorption on the way out would yield a total heat outflow from the stars larger than the observed 10 to 1 ratio.* In other words, if the stars are the sources of the observed cosmic rays, it follows from our measurements on absorption coefficients and on total energy content that the total heat output of the stars must be furnished by the atom-building processes going on in their merest outer skins of a thickness equivalent in absorbing power to about a hundred meters of water, and that therefore no atom-building processes, nor any other activities capable of furnishing heat, can then be going on in their interiors.

It is, however, so altogether absurd to suppose that atom-building processes are going on actively at the surface of a star, down to a depth of a hundred meters, and then suddenly stop there that we are forced back by this present mode of approach to the same conclusion arrived at from the direct determination of the lack of

[26] It is important to remember that, as we have already shown, rays of this kind become frittered away into heat in this passage through matter *without any change in the quality* (i. e., frequency or absorption coefficient) *of the residual beam.* This can only mean that *the conditions existing in and about the sun, and presumably also in and about other stars as well, are unfavorable to the atom-building processes which give rise to these rays.*

[27] Millikan, R. A., and Cameron, G. H., Phys. Rev. **28**, 866, 1926.

cosmic-ray activity of a particular star, the sun, namely, to the conclusion that *the observed cosmic rays do not originate in the stars at all, but that they must originate under the extreme influences of exactly the opposite sort existing in interstellar space.*

These considerations bring us then from two entirely new points of view to the conclusion that the heat output of the stars must be derived from an entirely different source from the atom-building processes which produce the cosmic rays. MacMillan [28] first, then Jeans [29] and Eddington,[30] from considerations based wholly upon the lifetimes of the stars, have repeatedly emphasized the necessity of finding a source for this output other and greater than the process of atom building, but we can now go further and say that the process of energy emission by atom building does not take place in the stars at all, or at least in such amount as to make the stars an appreciable factor in the output of cosmic rays, for if it did the star would have to be radiating heat much faster than is the case. As is well known, the foregoing astronomers, and practically all of the writers in this field have found this new source of stellar heat *not in an atom-building process, but rather in an atom-annihilating process* which they assume to be going on in the interior of stars, positive electrons being thought to be continually transforming their entire mass into ether waves in accordance with the demands of Einsteins' equation. As indicated above, we have sought in vain among our cosmic rays for a ray of penetrating power corresponding to this act. It will be recalled that the mass which disappears in the creation out of hydrogen of one gram-atom of silicon—this produced the hardest cosmic rays that we can say with certainty that we have yet observed, for the iron rays are still to some degree hypothetical—was 0.23 g. The complete annihilation of the mass of hydrogen would obviously then produce, in accordance with Einstein's equation, a ray having approximately four times (accurately $\frac{1.0778}{0.23}$ times) the energy and penetrating power of our hardest definitely observed ray. *Our failure to find this ray, however, is no argument at all against the existence of the process in the interior of stars where the pressures are colossal and the densities must be enormous.* Indeed our failure to find this ray means rather that, if the act occurs at all, as MacMillan, Eddington, and Jeans think it must, it is obliged to occur precisely in the interior of stars where the result-

[28] MacMillan, W. D. Astrophys. Journ., **48**, 35, 1918; also **51**, 309, 1920; also Science, **52**, 67, 1920; also Scientia, Jan. 26, 1923; also Science, 62, July 24 and 31, Aug. 7, 1925.

[29] **Jeans, J. H.** Problems of Cosmogony and Stellar Dynamics, Cambridge, 1919, p. 286; Nature, **116**, 861, 1925, and **121**, 467, 1928.

[30] Eddington, A. S. The Internal Constitution of the Stars, Cambridge, 1926, Ch. XI; also Nature, **117**, 26, 1926.

24034—29——16

ing radiation is hidden away behind an impenetrable screen of matter—a screen that transforms all its energy into heat before the ray can get out. If the cosmic rays originated within the stars they would of course be similarly screened.

On the other hand, that the atom-building processes responsible for the cosmic rays, as distinct from the atom-destroying process just considered, actually occur, as our experiments definitely show, *outside the stars*, or at least where the rays produced by them can get to us, and in an energy that is of the same order of magnitude as that of the heat poured out by the star, is an extraordinarily illuminating fact. For it suggests at once, when combined with the MacMillan-Eddington argument, the following incomplete cycle, each element in which now has the *experimental* credentials indicated in the parentheses;

(1) Positive and negative electrons exist in great abundance in interstellar space (see the evidence of the spectroscope);

(2) These electrons condense into atoms under the influence of the conditions existing in outer space, viz, absence of temperature and high dispersion (see the evidence of the cosmic rays);

(3) These atoms then aggregate under their gravitational forces into stars (see the evidence of the telescope);

(4) In the interior of stars—under the influence of the enormous pressures, densities, and temperatures existing there—an occasional positive electron, presumably in the nucleus of a heavy atom, transforms its entire mass into an ether pulse the energy of which when frittered away in heat maintains the temperature of the star and furnishes most of the supply of light and heat which it pours out (see the evidence of the lifetimes of the stars, MacMillan-Eddington-Jeans).

The foregoing is as far as the experimental evidence enables us to go; but the recent discovery of the second element of the above unfinished cycle, namely, that the supply of positive and negative electrons is being used up continually in the creation of atoms the signals of whose birth constitutes the cosmic rays, at once raises imperiously the question as to why the process is still going on at all after the eons during which it has apparently been in process—or better *why the building stones of the atoms have not all been used up long ago*. And the only possible answer seems to be to complete the cycle, and to assume that these building stones are continually being replenished throughout the heavens by the condensation, with the aid of some as yet wholly unknown mechanism, of radiant heat into positive and negative electrons. This has been urged for years by MacMillan. Indeed it is implicit in Einstein's 1905 equation unless

we deny the validity of the most approved form of statement of the second law. The effort to work out more fully the thermodynamic implications of this complete cycle is now being made by Stern,[31] Tolman,[32] and Zwicky,[33] as well as by ourselves.[34]

---

[31] Stern, O. Zeits. f. Elektrochemie, **31**, 448; 1925.
[32] Tolman, Richard C. Proc. Nat. Acad., **14**, 268, 348, 353, 1928.
[33] Zwicky, F. Proc. Nat. Acad. In press.
[34] Millikan, R. A., and Cameron, G. H. Phys. Rev., **32**, 533–558; 1928.

THREE CENTURIES OF NATURAL PHILOSOPHY [1]

By W. F. G. Swann, D.Sc.

Director, Bartol Research Foundation of the Franklin Institute

Three thousand years ago there died in Egypt a king. He was buried with much pomp and ceremony, and in the company of such material things as reflected the atmosphere of his time. After 30 centuries, untouched except for the minor vandalism of robbers, these relics speak to us the story of an age which has passed. They tell us of a skill in craftsmanship equal to our own, of a beauty in art and in concept of design such as wins the admiration of our most famous artists; and reading the evidence of a little act here and a little thought there, we begin to see a people such as we could well have known as friends—a people of whom who can say that if one of them were born to-day and raised with our children he would be distinguishable from one of us. Yet, neither in the age that knew Tutankhamun, nor in any of the ancient civilizations that have gone before or after, do we find any shadow of a concept of that great scheme of nature's laws which has unfolded itself so unsparingly in our generation.

If the period from the dawn of history to the present time be shrunk into a day, we shall find that 23 hours of that day are barren as far as natural philosophy is concerned, for it is only in the last hour that science was born; and, even as the human child develops in its struggles toward manhood, so this child of nature has grown, but with such ever-increasing strength that in the last 10 minutes of its existence, in the last 25 years of actual time, it has outshone all the accomplishments of its infancy and adolescence and has torn from nature more of her secrets than she has vouchsafed to man in the whole previous history of his existence.

Three hundred years ago we find the world just emerging from the state in which he who would search for the hidden truths of nature must contend with three great obstacles—superstition, the power of the church, and, last but not least, a conglomeration of fixed notions as to the way things should happen, built upon the pseudo-philosophical reasoning of bygone ages, reasoning founded

[1] Founders' Day Address, Swarthmore College, Oct. 29, 1927. Reprinted by permission from the Journal of the Franklin Institute, vol. 205, No. 1, January, 1928.

not upon experimental bases, but upon dogma evolved out of the imaginations of the philosophers.

The train of scientific thought was founded largely upon the hypothesis that the writings of Aristotle were to be the ultimate court of appeal in all matters of dispute, and wondrous indeed were some of the things which Aristotle and his disciples had said. A good example of some of their misty philosophizing is the proof given by one of them that the world is perfect.

> The bodies of which the world is composed are solids, and therefore have three dimensions. Now, three is the most perfect number; for, of one we do not speak as a number, of two we say both; but three is the first number of which we say all. Moreover, it has a beginning, a middle, and an end.

Toward the end of the fifteenth century we find young Galileo enjoying the princely stipend of 15 cents a day as professor of mathematics at the University of Pisa. It is true that the professor of medicine gets 30 times as much, and Galileo's parents had originally intended him to be a professor of medicine. But what does he care! For he is much interested in discovering the laws of falling bodies; and, in spite of the fact that Aristotle has said otherwise, he is contending that heavy bodies and light bodies fall at the same rate. In scientific circles much resentment is felt at such a revolutionary suggestion; for Aristotle, without appeal to experiment, has evolved out of the consciousness of his inner mind the decision that bodies fall at rates depending upon their weights. It matters not that young Galileo has ascended the leaning tower of Pisa with a one-pound weight and a hundred-pound weight and, in full view of the learned men of the day, has dropped them from the tower and found that they struck the ground together. For Aristotle has maintained otherwise, and science is the voice of Aristotle.

Neither is there more tolerance in the matter of astronomy. For Galileo has invented and constructed a telescope, and though he has received much honor from his university for this performance and has had his salary doubled there are many who not only refuse to accept what the telescope reveals but steadfastly refuse to look through it lest they should be convinced of the truth of that which they do not wish to believe. With this obnoxious machine Galileo has found that the moon has mountains like the earth, which robs that body of some of its individual importance. He has found spots upon that most perfect of heavenly bodies, the sun, but worst of all he says that Jupiter has four moons attendant upon him. This last conclusion is in a way to upset everything. Though too much of a man of progress to doubt the evidence of his own eyes, even the great Kepler is disturbed in his mind. For according to all prevail-

ing notions of the day there should be seven planetary bodies and no more—the earth, moon, Mercury, Venus, Mars, Jupiter, and Saturn.

Hear the argument of Francesco Sizzi, himself a Florentine astronomer, against this assertion of Galileo:[2]

> There are 7 windows in the head—2 nostrils, 2 eyes, 2 ears, and a mouth; so in the heavens there are 2 favorable stars, 2 unpropitious, 2 luminaries, and Mercury alone undecided and indifferent. From which and many other similar phenomena of nature, such as the seven metals, etc., which it were tedious to enumerate, we gather that the number of planets is necessarily 7.
>
> Moreover, the satellites are invisible to the naked eye, and therefore can have no influence on the earth, and therefore are useless, and therefore do not exist.
>
> Besides, the Jews and other ancient nations as well as modern Europeans have adopted the division of the week into seven days and have named them from the seven planets; now, if we increase the number of planets this whole system falls to the ground.

You can judge of the wrath and indignation which Galileo brought upon his head when he contended in reply that whatever might be the force of these arguments as a reason for believing beforehand that no more than seven planets would be discovered, they hardly seemed of sufficient weight to destroy the new ones when seen.

It was Galileo who wrested from nature the secret of the laws which govern motion—the laws which govern the motions of almost everything, the planets in the heavens, the flywheel of the steam engine, the bird in flight—yes; and in a large measure at any rate, the motions of the innermost parts of the very atoms of matter itself. But Galileo did not evolve these laws out of the dogmas of imagination but by the more humble and safe appeal to direct experiment. He marked out the method of approach, the experimental method, which has been the model for all succeeding generations in their search for the fundamental facts which govern the workings of nature.

The laws of motion may be written on a post card, but their consequences have not been exhausted in all the books men of science have written in 300 years. As we all know, Galileo's life was beset with tribulation. He lived in an age when there was little tolerance for one who followed not the conventionalities of thought of the day. To question the learning of the past was arrogance, to discover new truth was blasphemy, and so he died, having sown, however, the seeds of the fruit that was to come. He died in a world seething with superstition and ruled by the dogmas of an ancient past, but a world which was destined only a year later to see the birth of one who is rated by many as the greatest genius of all time, that great prince of England's men of science, Isaac Newton.

---

[2] Quoted from Sir Oliver Lodge's Pioneers of Science.

In its purest aspect the task of the natural philosopher to-day is to discover the relationships existing between the different phenomena which happen in our universe. He seeks to see in the workings of nature simply different illustrations of a few fundamental principles. Newton was the greatest of the pioneers in this method of systematized thought. In his great work, the Principia, characterized by Marquis Laplace as preeminent above all productions of the human intellect, he demonstrated the powerful simplicity of the fundamentals which control the destinies of the heavens. No longer did the universe appear as a bizarre and formless thing governed by such a heterogeneous system of agencies as to merit well the caustic comment of the sovereign of Castille, when, bewailing the complexities involved in an attempt to explain the motions of the planets, he remarked that "Were the heavens thus constituted, he could have given the Deity good advice."

No longer need the sun carry spokes, as Kepler thought, to grind the planets around in the heavens. No longer was a guardian angel necessary for each planet to guide its course. No longer were the planets whirled through space by the whirlpools of an ether as a twig is whirled about in the rapids. All that was necessary was the laws of motion of Galileo, operating under the influence of a force emanating from the sun according to the inverse square of the distance therefrom. And this force was no new and mysterious thing, for Newton showed that gravitation, that same old force which had been known for so long—gravitation which causes apples to fall from the tree to the ground—was sufficient to control the moon in its orbit, and such a gravitation with its origin in the sun served the purpose of controlling the planetary motions. Moreover, in this same gravitation did the tides find their origin through an attraction of the moon. In this same gravitation from the sun, combined with the flattened shape of the earth, did that mysterious conical motion of the earth's axis concerned with the precession of the equinoxes find its origin, and in the laws of Galileo was to be found an explanation of the actual flattening of the earth's shape as a result of the centrifugal force of its rotation. These and many other things did Newton demonstrate in the "Principia" and by their means brought astronomy from a state of pure charlatanism to the state of order symbolized by Pope's famous words, "Nature and nature's laws lay hid in light, God said: 'Let Newton be' and all was light."

Even as our greatest architects strive for beauty couched in a fundamental simplicity of design, so the Grand Architect of the universe revealed himself in Newton's great work as the father of the principle of dignity of structure through ultimate simplicity. It is a great faith in the possibility of seeing in the operations of nature the working of principles which are ultimately simple which, as each new

discovery is revealed, has encouraged man to the hope that he may some day understand them.

While to-day nature has revealed many treasures unknown to Newton, there are few who, realizing the great stride made in the "Principia" will not to-day join with Halley in his eulogy of that great work, "So near the gods man can not nearer go."

When an outstanding genius causes science to take a leap forward beyond the vision of his contemporaries, there usually follows a period of depression in which it seems that all that is worth doing has been done, and that what the universe has not already revealed must forever defy the power of man to fathom. Such a period followed Newton. Of course, much valuable work was done in the years which came after, but it took more the form of a development of the consequences of Newton's labors than of the discovery of new paths of knowledge. And then, only about a century ago a new page in the architectural designs of the universe was turned, and the heading on that page was *electricity*.

The forerunners in the march of science do not often come heralded by much ceremony suggestive of the power that lies behind them. Often in apparent trivialities do they reveal themselves—trivialities so void of spectacular content that but few can be found who deem it worth while to listen to their story. A hundred and fifty years ago little more was known of the science of electricity than the fact that if a black rod is rubbed with the skin of a cat it will acquire the power to pick up small pieces of paper, and, if viewed in the dark, will be found to emit a blue glow. One can hardly imagine a set of phenomena more vulnerable to the scoffer; for black rods and cats have been the stock paraphernalia of witches from time immemorial—the blue light visible in the dark adds no particular prestige to the phenomena. And then we find that these things will not reveal themselves in the presence of water. Now, we should say that water destroys the electrical insulation, but the scoffer who had heard so much of the fundamentality of that triumvirate, "earth, fire, and water," might find ample wherewithal to whet his sarcasm, and even though he should admit the reality of the phenomena themselves, he might well attack them on the basis of their futility, for it would appear that if all the black rods in the world were rubbed with the skins of all the cats the most that might hope to be accomplished would seem to be the raising of a small weight of totally insignificant amount. And yet, on this earth at that very time there existed, and within the reach of man, the wherewithal to make a dynamo.

To one who contemplates the enormous manifestations of electrical power to-day, it seems almost inconceivable that all of these

potentialities could have remained dormant for the whole period of man's civilization.

The Royal Institution of Great Britain was founded by Count Rumford in 1799. Its stated purpose is "the promotion, diffusion, and extension of science, and of useful knowledge." To its lectures given by Sir Humphry Davy at the beginning of the last century came a young bookbinder's apprentice, whose enthusiasm sufficiently impressed the lecturer to result in his being appointed as assistant at the institution. Unfortunately, it became necessary for the young man to have some money wherewith to live, but there was no money for scientific assistants. However, the institution had an appropriation for janitors and so the bookbinder's apprentice, Michael Faraday, became janitor at the Royal Institution. I do not know how efficiently he performed his duties in the office of janitor, but even though he may have neglected the windows of the laboratory he cleaned well the windows of science, and even though he may have neglected the cobwebs on the walls of the building he cleaned many of them from the horizon of knowledge.

The fact that wires carrying currents possessing in many respects the characteristics of magnets was already known, but it fell to Faraday to discover the fact that batteries were not the only means by which electric current could be produced, and to demonstrate the fundamental principles upon which electrical engineering is based to-day. By the labors of that little group of men, Ampère in France, Faraday in England, and Henry in this country, we came into possession of most of the facts governing the broader features of electrical science,—the facts which tell us how to build a dynamo, a motor, and the like. We came to know of strange new forces with mysterious relations between them. But what was their explanation—what was the secret of their mutual relations—of what broad principles of the design of the universe did they form a part? Then came Clerk-Maxwell, who sought to correlate these discoveries into a more harmonious unity.

Maxwell was a great mathematician; and, as a result of his labors, he wrote a book which few could read, but which, in the years that have followed, has served to mold our thoughts to that comprehension of the subject which we enjoy to-day.

The place of the mathematician, of the dreamer, in natural philosophy, is not always apparent to the layman. He takes the facts which the experimenter gives him, and seeks to correlate them as part of a greater framework of truth in the hope that the frame itself shall suggest other things which may be true, and thus stimulate further search, and widen our comprehension of the whole. A man coming to us from another country, or from another world might, by observing the actions of our President, our Secretary of Labor, and

the governor of one of our States, form some sort of an opinion as to the probable actions of these individuals under given circumstances. His understanding of the whole situation would, however, be much less complete than it would be were he acquainted with the whole mechanism of our Constitution, or even with some part of it which was fairly complete in itself. If his knowledge is confined within the limits we have supposed, however, he might take such information as he had, and try to reduce it to some sort of order by building in his mind a constitution of which such individuals as he knew formed a part. In this creation of his mind, he would have to picture many new individuals and offices in order to complete the framework of his thought. He would naturally suggest a search for these individuals. Every additional one found would add more certainty to his general plan, while every one he failed to find would give him a clue as to how his plan should be modified in order to conform to the facts. When all was complete, or, indeed, long before all was complete, long before he knew the status of every minor clerk in the Government's employ, he would be conscious of a much better understanding of the whole situation, and would be in a much better position to draw upon the services of the Government than he was when the whole of his knowledge was confined to the actions of the three individuals we named at the start. If this man, who corresponds to our mathematical physicist, should now go back to his own people, he would doubtless have much difficulty in making them understand the plan of our Government. The facts they would have to accept, but it might be only after prolonged experience of our actions that the mechanism of our procedure would enter into their inner consciousness with that force which implies understanding.

So, Maxwell sought and found a beautiful scheme of thought in which to comprehend and harmonize the discoveries of his predecessors. The form of his scheme was such as to suggest that it should be possible to propagate electromagnetic disturbances in the form of waves in an all-pervading medium, and that certain of these waves should have the properties of light waves, and that all should travel with a velocity equal to that of light. His conclusions in the latter respects were beautifully verified by his calculation of the correct velocity of light from purely electrical data, and his predictions in the former have received wonderful justification, first in the experimental work of Hertz and Lodge, and finally in the modern developments of wireless telegraphy and telephony in the hands of Marconi and others, developments which at every stage of their progress have drawn upon the principles outlined in Maxwell's great work. We now know that the electromagnetic waves of wireless, heat rays, light rays, the ultra-violet rays used thera-

peutically, X rays, the gamma rays emitted by radium and the cosmic rays of which we have heard so much recently, are all special cases of electromagnetic waves differing from each other in their essentials only as regards their length. The longest are the wireless waves, which attain lengths of the order of a mile, and the shortest constitute the cosmic rays, whose length is comparable with the one-millionth of the one-millionth of the centimeter.

And then, following Maxwell, once again science made one of those pauses for breath in which many seem to see the end of all that man may hope to know—those dread pauses in which the horizon of discovery seems the boundary thereof.

Thirty years ago was a time of great depression in physics—a time when would-be Ph. D.'s went about like roaring lions seeking something to measure and finding nothing but the density of a gas or the viscosity of a solid. The sentiment of the times was well voiced by a certain European physicist of eminence who stated that it was probable that all the important experimental discoveries in physics had then been made and that henceforth the investigator must confine himself to a repetition of what had been already done with greater attention to minor matters of precision.

Even in those days the apparatus cases of most laboratories contained curiously shaped glass tubes containing rarefied gases of various kinds which could be made to glow in fantastic manner by sending an electric discharge through them. Few sought to penetrate the mysteries of those tubes. They would be brought forth on the occasion of popular exhibits in the laboratory, made to go through their alluring performances and then returned to their cases to await the next festivity of the kind. They were not viewed as serious articles of scientific research, but hardly as more than toys. And yet, what a marvelous secret they held! For it was in one of those tubes that, in 1898, J. J. Thomson discovered one of the two fundamental bricks out of which the universe is built—the electron, the tireless worker whose home is in the atom, whose quivers send us light from the sun, whose ceaseless flight around the atom's center gives the magnet the power to pull, whose motion through the electric cable constitutes the electric current, whose splash when hurled into the atom with great speed is the X ray, whose motions in the antenna send us wireless waves, and whose motions in the radio tube enable us to detect those waves. It is to the electrons that matter owes all its chemical properties. It is electrons from the sun which are responsible for the aurora. The atoms of which matter is composed are so small that about a hundred million of them laid in line would take up but the length of one-third of an inch, but the electron is so small that even in comparison with the atom it is but as a fly compared with a cathedral. It is so light that if

everything were magnified in mass so that the electron attained a mass of four ounces, that four ounces would on the same scale of magnification become as heavy as the earth.

Before the discovery of electrons we had cause to believe that there were such things as atoms and molecules, but nobody ventured to picture their structure, and we felt we had gone far in penetrating nature's mysteries when we were able to say that, on the basis of certain plausible considerations, it was probable that if a drop of water were magnified to the size of the earth, the molecules would become as large as small shot. The discovery of the electron gave a fresh impetus to man's hope of understanding the atom, and before long the second fundamental brick of nature's structure revealed itself—the fundamental unit of positive electricity—the proton, whose natural home is in the nucleus, the heart of the atom. The proton is two thousand times as heavy as the electron, but it is two thousand times as small, so that if the proton were magnified to the size of a pinhead, that pinhead would, on the same scale of magnification, attain a diameter equal to the diameter of the earth's orbit around the sun.

At the end of the last century Röntgen discovered X rays. The property by which they first claimed attention was their power to pass through flesh and so show shadows of the bones of the body. Soon, however, it was realized they were endowed with many other properties of a most important and interesting kind, properties which were bound up with the atom's structure and whose study, therefore, served to throw further light upon that structure.

Until the end of the last century, one of the most firmly established beliefs was that of the permanence of the atoms. However, near its close, Becquerel found certain curious properties of uranium oxide which suggested that this substance was continually emitting some kind of a radiation which could pass through screens opaque to light, and affect a photographic plate. Several other substances were discovered possessing this property, and many other characteristics of these substances were discovered, characteristics which could only be harmonized on the belief that the atoms of these substances were in a continual state of spontaneous disintegration—of atomic explosions if you will—and that the phenomena observed were the symbols of these explosions.

One may naturally be led to inquire how far discoveries in pure physics and mathematics find their reflections in the things of everyday life in the sense which we call useful. If in a great city we should set out on our travels with the intention of visiting all the places within the field of our immediate interests to the exclusion of others, and if we should refuse to walk along any street which did not itself contain many of these places, then, even as regards those

things to which our interest was confined, we should limit greatly the possibilities which that city opened to us. If this is true of a relatively simple structure like a city, how much more is it true of that beautiful framework of science whose parts are so clearly interwoven that it is almost impossible to touch one of them without producing response in all the others. While, therefore, the man of science must pursue knowledge for its own sake, it is a remarkable fact that practically all of those achievements in the physics of the past 20 years which might be classed as utilitarian, have arisen directly from, or in relation to investigations pursued with no utilitarian motive directly in view. X rays revealed themselves first in the light of their importance in surgery. The study of their properties shed a new light upon the structure of the atom and this light was reflected back with enhanced intensity to clarify the properties of the X rays themselves. The immediate application to photographic surgery was obvious, but that field which is concerned with the effects of the rays upon the body tissue, upon the cure of cancer and the like, was not so evident. Bound up as it is with the properties of the rays in relation to their passage through matter, with their absorption in the tissues, and the extent of the molecular disruption which they produce, it must draw for its development upon the more fine-grained aspects of the study of X rays which the physicist has made in the field of his own interests.

The study of radio-activity has taught us that in the spontaneous disintegration of the atoms which accompanies this process, powerful radiations are emitted. First we have the alpha particle, a positively charged atom of helium, with a velocity of 12,000 miles per second. Then we have electrons traveling with a velocity 10 times as large, and finally we have a very hard type of X ray known as gamma rays. These rays possess the power to disrupt molecules through which they pass and it is this power which gives them, in common with X rays, such great value in medicine. The surgeon's knife can dissect the tissues and remove the larger malformations of growth, but the X rays, the rays from radium, and those of ultra-violet light can dissect the malformation on things ten thousand times smaller than the smallest things which our microscope can reveal.

The detailed investigations of phenomena pertaining to the passage of electricity through gases—phenomena whose study led to the discovery of the electron, necessitated an improvement in our methods of producing high vacua. The pumps of to-day can accomplish in 15 seconds what would have taken a couple of hours 25 years ago, and the vacua attainable are ten thousand or more times better than they were in those days. We can now reduce the pressure in our apparatus by means of modern pumps to such an extent that only one in

every hundred thousand million of the molecules originally present remains. This improvement in the technique of producing high vacua, rendered necessary for investigation in pure science, has rendered possible the electric lamps which we use to-day. It has rendered possible the modern X-ray tube—an instrument not only infinitely more reliable than the weak and capricious tubes of 20 years ago, but controllable in intensity to amounts twenty times as great as those formerly attainable. It is only through the aid of modern vacuum technique that the modern broadcasting station has been rendered possible, that the radio amplifying tube has become a reality, and that we can have wireless transmission of signals, speech, and photographs.

If, 20 years ago we had wished to give an example of a type of research which was least likely to have an utilitarian value, we could hardly have chosen a more fitting example than the investigations which Prof. O. W. Richardson had been carrying on in England, and later at Princeton, on the emission of electrons from heated wires; yet it is to these investigations, combined with the power to produce high vacua, that we owe the modern radio tube, the X-ray tube, and a variety of appliances used in the general fields of radio transmission and X-ray technique.

It has long been known that light when falling upon the surface of certain substances possesses the power to eject electrons from them, and the study of this phenomenon has been one of primary importance in relation to our knowledge of atomic processes. But it, too, has had its practical application, for it is this phenomenon which has rendered possible the wireless transmission of pictures, and a variety of other things hardly less important even though less spectacular.

Many years ago, Rowland, of Johns Hopkins University, showed us how to rule very fine closely spaced parallel lines on speculum metal, and use them to analyze light into its component colors. That which the grating does to the light can be predicted if we know the spacing of the lines; and, conversely, if we had known beforehand the nature of the light, we could have gained information regarding the spacing of the lines. Since X rays are of the same general nature as light, but of much shorter wave length, it became a matter of interest to inquire how far such methods could be applied to them. It soon appeared, however, that for the successful pursuit of this problem, it would be necessary to rule lines whose distance apart was of the order of one hundred-millionth of a centimeter. We can not, of course, make such ruling, but nature has provided us with something very like them in the regularly spaced atoms which constitute a crystal of rock salt, for example. About 15 years ago, Laue found that he could make a crystal act in relation to X rays in very much the same way as Rowland's gratings acted toward light. The matter

was pushed rapidly forward by a number of physicists, and soon gave accurate means of measuring the form of distribution, and spacing of the very molecules of the crystals. It is quite impossible in a short space to give any idea of the tremendous field of activity which these discoveries opened up in relation to atomic structure on the one hand, and the nature of X rays on the other. Not only this, but it soon became realized that there were other fields of usefulness for the new method. Not the least among these has been its application to the structure of metals, which has provided the metallurgical engineer with a new method of attack in the detailed examination of his alloys, and of the effect of strain and other treatment upon them. Whereas formerly the limits to the fineness of his examination were determined by what his microscope could see, he is now almost in a position to look at the very molecules themselves.

Many years ago, Professor Michelson, of the University of Chicago, became interested in the question of whether or not the velocity of light is affected by the earth's motion. This is an experiment having, at first sight, nothing but a philosophical interest. But Professor Michelson obtained an unexpected result, a result which did not harmonize with our understanding of nature's laws; and herein lay its great value, for it showed that our modes of thought required revision. This great revision, not, of course, in the laws themselves, but in the sense in which we interpret them if they are to harmonize throughout, constitutes the theory of relativity—a way of looking at things which soon made its influence felt outside of the domain in which it was born—a scheme of thought which has enabled us to see harmony in, and so understand, many wonderful things in the theory of electricity, atomic structure, and other branches of physics. Moreover, here again, we meet with a remarkable example of the interdependence of the various parts of science on each other. Of all branches of pure mathematics one could hardly conceive any farther removed from nature than those having to do with noneuclidean geometry, and the so-called absolute calculus of Ricci and Levi-Civita. These were fields so specialized as to be studied only to a very limited extent by mathematicians themselves. Yet, even as an archeologist might suddenly come upon a scroll of papyrus outlining the laws of an ancient civilization, and might therein find the means to harmonize, and understand the other visual records which his search had unearthed, so Einstein found in these abstruse writings of the mathematicians the wherewithal to express the unity of nature's laws in a form so beautiful that he has likened that expression to a wonderful symphony of which our universe is the expression of God's rendering.

Astronomy, the most ancient of the sciences, has always occupied a place in the forefront of the imagination of the scientist and the layman alike. With the motions of the planets coordinated by Kepler, and molded into a beautiful scheme of physical law by Newton 300 years ago, there seemed but little more that man could expect to discover. The growth of the science of optics soon provided a tool wherewith to explore farther, however. Laboratory studies of the nature of the light emitted by incandescent solids and gases soon provided a means of determining much concerning the heavenly bodies by a study of the light which they emit. Stars which are so far away that their light, traveling toward us at the rate of 186,000 miles per second, takes thousands of years to reach us, may move with great velocity without that velocity making itself apparent by direct observation. A study of their light has enabled us to determine their speed in very much the same way that we could determine the speed of a train by noting how much the pitch of its whistle is altered by the motion.

The stars are so far away that even in our most powerful telescopes they appear but as points in spite of their great size; but by drawing in greater detail upon our knowledge of the way in which light comes to us and of the effect of the size of the emitting body on the character of the light, Professor Michelson, at an age when most men are content to rest upon their laurels, performed one of the most brilliant feats of a lifetime of masterly achievements in measuring the diameter of one of these stars, a feat equivalent to measuring the diameter of a penny at a distance of a thousand miles.

Strange as it may seem that we can learn so much about the stars which are so far away, the last few years have enhanced still further the wonder of it all. For the knowledge which we have gained about matter by experiment in the laboratory has found a most remarkable field of application in enabling us to understand the conditions which must prevail in the stars; and, these stars by their peculiar characteristics of large size, high temperature, high density, etc., have provided us with conditions to test out conclusions such as we could never have hoped to attain in the laboratory. A gas compressed to a density eight thousand times that of steel is but a figment of the imagination in the laboratory, yet of such stuff is the companion of Sirius made. Temperatures of 40,000,000° correspond to things ten thousand times as hot as any temperatures we find on earth, yet nature has realized such temperatures in some of the stars. And so the stars, far from being things through which we dare hope to learn but little have, by their exceptional condition, served to provide us not only with a very fascinating story of their own

life history, but with a large part of the story of the birth of matter itself.

Discoveries in the fields of experimental science naturally go hand in hand with that study of the laws of design of the universe which we call theoretical science. One supplements the other, and the strength of one enhances the strength of the other. It is naturally around the atom's structure that the thoughts of men have loved to hover. And here, the power to comprehend a new point of view has grown enormously in the last few years. We have a clearer understanding of what understanding means. We were in danger of becoming so enamored of those laws which govern the behavior of matter in bulk as to refuse to admit any other possibilities in respect to the laws of the atom. The workings of the coarse-grained things of nature were all about us. Pulleys, springs, water torrents, the waves of the sea, these were things of common experience, and the mind sought contentment in the thought that the atom might utilize in its structure only things which behaved as these things behaved; and even as a little hill may hide the Alps from one whose life is in its shadow, so there was danger in the known and obvious workings of the common things around us obscuring from our vision the story of that great universe of the atom which lies beyond. Happily, the complacency of our outlook has received, in recent years, one or two serious jolts. First came the theory of relativity, which taught us that a greater elasticity of thought was necessary if we were to understand nature as she is rather than as we might have made her. Then came a series of experimental phenomena which seemed to violate all our notions of how things should be, and since we could not alter the experimental phenomena we had to alter the notions, and so there arose the so-called quantum theory of atomic structure—one of the most helpful crystallizations of thought for correlating the facts that we have ever had. And then, as further search showed this theory to be inadequate beyond a certain stage, there arose only a couple of years ago, an entirely new way of regarding the atom—a way so radical in its point of view that it is safe to say that had it been put forward 15 years ago, it would hardly have attained a hearing. Born in a day of more liberal thought, however, it had no sooner made an appearance than a host of workers arose to welcome it and to develop its consequences, so that to-day there is hardly a physical laboratory in the country which does not contain one or more persons who have acquired the power to think in its terms.

In speaking of theories being discarded and superseded by others, we must not think of the discarded ones as useless. The situation is not one where we are to think of a certain theory as right

and all the others wrong. In a sense, different theories are like different languages for describing the same phenomena. The English language may be more suitable—more powerful for the purposes of the science of chemistry than the French language. It may have a greater richness of word content; but to say that one is right and the other wrong is to utter nonsense.

And so, a quarter of a century after the prediction of the eminent European philosopher to the effect that discovery was ended we find ourselves in the most intensive period of scientific activity of all time. We may well ask where we are headed. Shall we continue to discover new treasures, or, when we have catalogued those we have, shall we reach again one of those periods of stagnation? If we do, and if there be any one who then feels that progress is ended, that knowledge is complete and that science is dead, let him think of how confidently he could have voiced that same thought in the civilization of the Pharaohs. Let him think with what surety he would have voiced it in the years which followed Newton. Let him think how he would have voiced it—yes, perhaps how he did voice it 30 years ago, and then let him take hope. For, the words of the Bard of Avon are truthful yet; " There is more in heaven and earth than is dreamed of in " even twentieth-century philosophy, and the richness of nature's content will not be fathomed in our time.

THE HYPOTHESIS OF CONTINENTAL DISPLACEMENT [1]

By Charles Schuchert

Professor Emeritus of Paleontology and Historical Geology, Yale University, New Haven, Conn.

[With four plates]

"God has delivered the world to the disputes of men"

Wegener's hypothesis first appeared in 1912 in Petermann's Mitteilungen and in the Geologische Rundschau. In 1915 came his book, Die Entstehung der Kontinente und Ozeane, with a second edition in 1920, a third in 1922, and a translation into English in 1924. The hypothesis did not receive much consideration from English-speaking geologists until 1922, when Lake reviewed the book at length in the Geological Magazine of London, and the next year lectured on the hypothesis before the Royal Geographical Society. In the same year, Reid reviewed the book in the Geographical Review of New York. The theory was likewise discussed before the British Association for the Advancement of Science in 1922, and the discussion reported in Nature by W. B. Wright, while a similar discussion by geologists, zoologists, and botanists before the Royal Society of South Africa appeared in the same periodical. Since then the hypothesis has been dealt with further in Nature and elsewhere. For the benefit of Americans, the more important discussions in English are enumerated below.[2]

[1] Reprinted, with slight alterations and additions, from Theory of Continental Drift, 1928, by permission of the author and the American Association of Petroleum Geologists, Tulsa, Okla.

[2] F. B. Taylor, Bearing of the Tertiary Mountain Belt on the Origin of the Earth's Plan, Bull. Geol. Soc. Amer., vol. 21 (1910), pp. 179–226; Movement of Continental Masses Under Action of Tidal Forces, Pan-Amer. Geol., vol. 43 (1925), pp. 15–50; Salient Points in Tertiary Epeirogeny, Bull. Geol. Soc. Amer., vol. 38 (1927), pp. 107–109.

A. Wegener, The Origin of Continents and Oceans. Translated by J. G. A. Skerl, and with an introduction by J. W. Evans, Dutton, 1924.

Philip Lake, Wegener's Displacement Theory, Geol. Mag., vol. 59 (1922), pp. 338–346; Wegener's Hypothesis of Continental Drift, Nature, Feb. 17, 1923, pp. 226–228.

W. B. Wright, The Wegener Hypothesis, Nature, Jan. 6, 1923, pp. 30–31. This discussion, before the British Association, was "lively but inconclusive," but all were agreed that the Atlantic Ocean was much older than Pleistocene time. It led to other papers in Nature for Jan. 27, 1923, p. 131; Feb. 24, 1923, pp. 255–256; Mar. 24, 1923, pp. 393–394; Apr. 25, 1925, p. 602; May 30, 1925, pp. 834–835; Sept. 26, 1925, p. 481.

J. W. Gregory, Continental Drift, a review of Wegener's book in Nature, Feb. 21, 1925, pp. 255–257.

W. K. Pickering, The Separation of the Continents by Fission, Geol. Mag., vol. 61 (1924), pp. 31–34.

Arthur Holmes, Continental Drift, a review of Theory of Continental Drift, Nature, Sept. 22, 1928, pp. 431–433.

Philip Lake, review of the same book, Geol. Mag., Sept., 1928, pp. 422–424.

ABSTRACT OF WEGENER'S HYPOTHESIS

As Dr. van der Gracht has treated the Wegener hypothesis at length [3] it will not be necessary here to go into it again fully; all that will be needed is to state briefly the main points of the theory:

(1) The earth is not a shrinking mass.

(2) The amount of water on the earth's surface has always been the same.

(3) Early in the history of the earth there was a thin universal granitic shell which before the Silurian had been thrust and folded into a greatly thickened continent that he calls Pangaea.

(4) The continental blocks (Pangaea) underwent great horizontal drifting movements in the course of geological time, and these presumably continue even to-day. The rifting probably began in Paleozoic time, but it was not until the middle Jurassic that Australia-Antarctica began to separate and drift southeast. In the early Cretaceous, the Americas began to move westward and finally, in the Pleistocene, Greenland-Newfoundland was separated from Norway and Great Britain.

(5) The separated continents of to-day, when moved together, working on a globe, fit against one another as do the pieces of a jig-saw puzzle.

(6) The poles of the earth have in the past slowly wandered about, and in Permian time they were as much as 2,500 miles from their present positions.

(7) The mountains of the earth are in the main not due to a shrinking earth but to the drifting of the continents, one set arising at the edge of the forward-moving granitic continents where they come against the resisting basaltic shell, as best exemplified by the Cordillera of North America and the Andes of South America; while those of the Euro-Asiatic continents are due to a "striving toward the equator of the continental blocks," namely, the movement toward each other of the Euro-Asiatic mass and the African one.

(8) Wegener holds firmly to the theory of isostasy, and accordingly believes that the land masses, large or small, can not sink and vanish into the heavier basaltic layer. He does away with land bridges across the oceans by uniting all lands into a Pangaea.

(9) Accordingly, Wegener rejects the theory of the permanency of oceans and continents as we see them to-day.

---

[3] Theory of Continental Drift, 1928, pp. 1–75.

THE MAKING AND BREAKING OF PANGAEA

THE TIME ELEMENT

The rifting of Pangaea and the floating away of Australasia, Antarctica, and the Americas are said to have begun east of Africa in Jurassic time and west of Euro-Africa in early Cretaceous time (Pl. 1). These dates are based at best on insecure paleontological evidence; nevertheless let us accept the hypothesis to see what it leads to along other lines of geological inquiry. We are to believe, under this supposition, that this immense rifting and drifting of the continents went on during one of the earth's most marked times of crustal quietness, the early and middle Cretaceous, when almost no mountains were made in the whole world—a time almost devoid of volcanic activity, when the continents were about as peneplaned and low as they ever have been, and when they were flooded by the greatest oceanic transgressions of all times. The drifting continued during almost the whole of Cretaceous time, which, on the basis of radium disintegration, means for 65,000,000 years, before the continents showed any marked crustal unrest, or even marked volcanic activity. Wegener's theory emphasizes accumulating or lagging effects in the crust, but why a lagging of something like 50,000,000 years?

On the other hand, Pangaea must have endured unbroken all through the Proterozoic, or if it did not exist as early as this, at least it was present during all of Paleozoic time; yet two of the earth's greatest times of mountain-making came toward the close of the Proterozoic and of the Paleozoic and each was accompanied by a glacial climate. Why was Pangaea not broken up at these times of marked crustal unrest, and why did it break up in one of the times of greatest crustal stability? Of course, all of this is as determined by orthodox geology. Wegener's hypothesis calls for floating continents in a viscous substratum, all whirled to the east, and he compares the continental blocks to icebergs floating in water. Why, we ask again, was Pangaea not broken up during the Pennsylvanian-Permian? Was it the making of the late Jurassic Mountains of wide extent in North and South America that started the fracturing of this combined land mass? If so, why did not the time of greater mountain making during the Pennsylvanian and Permian also have the same effect? On the other hand, it will not do to say that Pangaea came into existence during the Devonian or Silurian, since orthodox geology teaches that the continents of to-day were, in their main features, already present in late Proterozoic time.

Daly,[4] in his new book, says:

Neither Taylor nor Wegener has shown why the continents should move. They have not discovered the force which did the gigantic work of overcoming the resistances to continental migration. Nor have they evaluated these resistances. For these reasons geologists are going slow in placing such mobility of continents among the accepted principles of science.

THE JIG-SAW PUZZLE

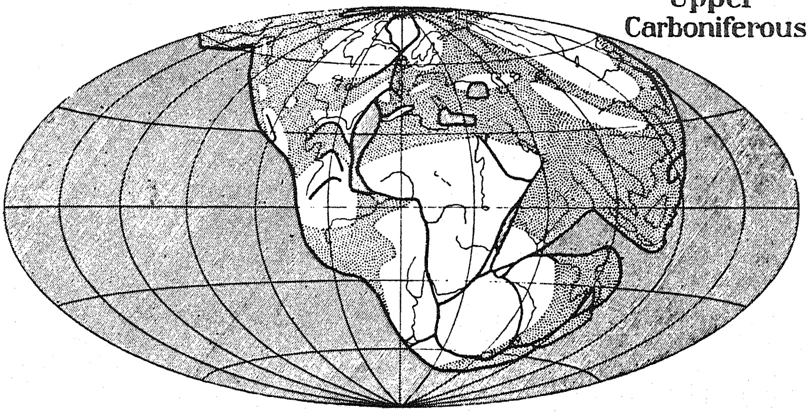
Let us for the time being agree with Wegener that the Americas have broken away from Euro-Africa and that their present shore lines and shelf seas are practically those of the Cretaceous riftings, and see what these assumptions will lead to. If we take an 8-inch globe and squeeze upon it over the Americas a quarter-inch layer of plasteline, cut this out into the shape of these continents but at the outer edge of the continental shelf, and then shift this plasteline replica over against Euro-Africa, following the instructions of Wegener that Newfoundland must be placed beside Ireland and Cape San Roque of Brazil fitted into the Bight of Biafra in Africa, the resulting geography shows Central America about 1,200 miles away from Africa and leaves Siberia and Alaska separated by about 600 miles! And these are not the only discrepancies, for the North Atlantic Ocean (Poseidon) becomes much larger and of a totally different shape from that shown by Wegener; and furthermore, the Sierras of Argentina not only take on a northeast strike but are also about 350 miles northwest of the place where they are supposed to connect directly with the east-west trending Cape Mountains of Africa. These facts are shown in Plates 2–4, and should be compared with Wegener's results illustrated in Plate 1 and Behm's in Figure 1. It is evident, therefore, that Wegener has taken extraordinary liberties with the earth's rigid crust, making it pliable so as to stretch the Americas from north to south about 1,500 miles, and the greatest stretching is done in Central America. The smoothing out of all the mountains will at best not reduce this discrepancy by more than 500 miles.

Diener, in 1915,[5] in criticism of the displacement theory, directed attention to the fact that when one shoves North America eastward against Europe there results a great cleft and a deep ocean between Siberia and Alaska. He was in error, however, in stating that the opening would be 35° across, due to his working on a Mercator map; by the plasteline method, previously described, we find that the opening is nevertheless about 600 miles wide. Such an opening brings back in full force Diener's criticism, and alone is fatal to Wegener's hypothesis, because since early Cambrian time

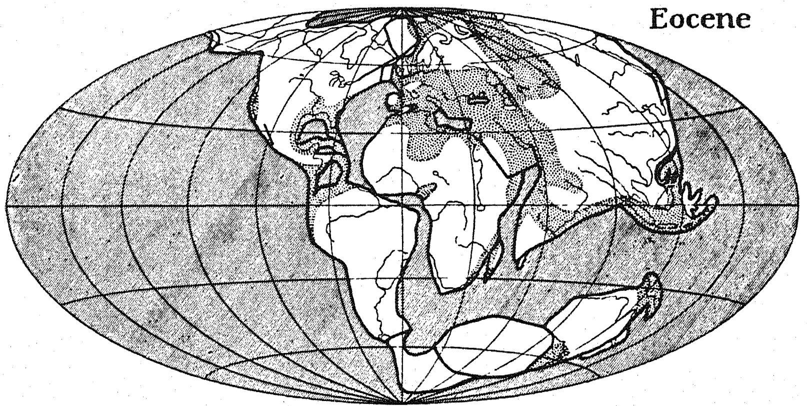
[4] R. A. Daly, Our Mobile Earth, Charles Scribner's Sons, 1926, p. 263.

[5] Carl Diener, Die Grossformen der Erdoberfläche, Mitt. k. k. geogr. Gesell., Wien, vol. 58, pp. 329–349.

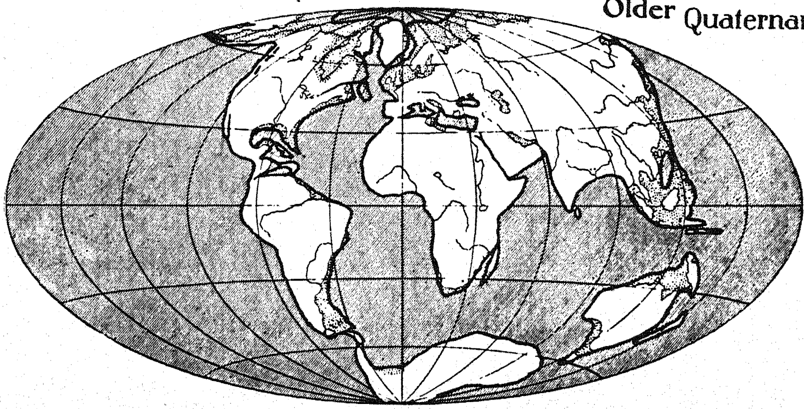
Upper Carboniferous



Eocene

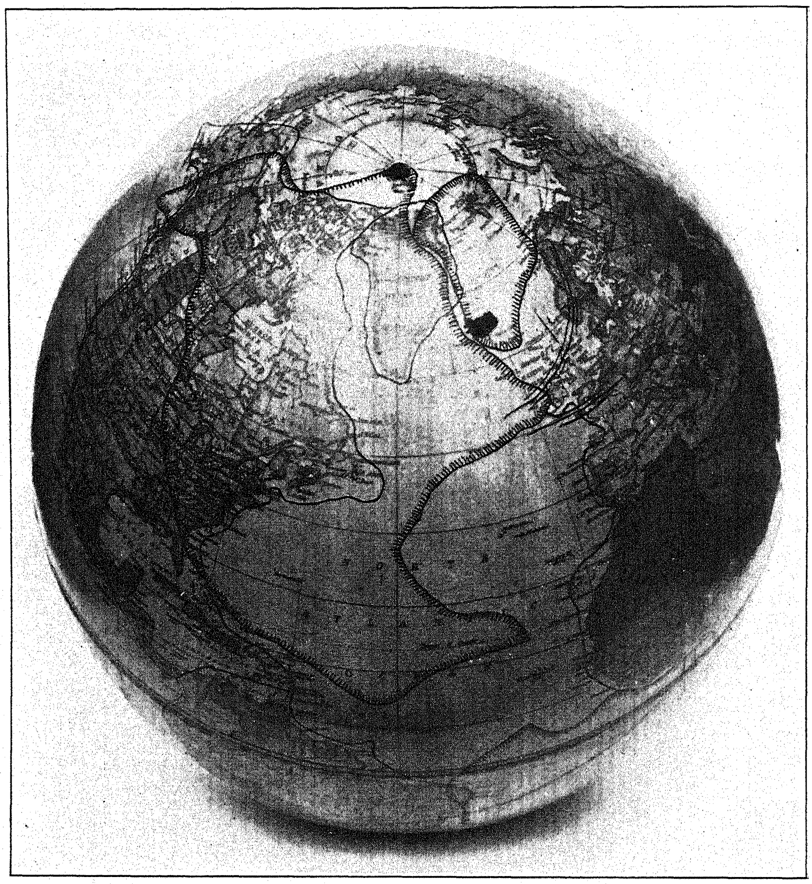


Older Quaternary



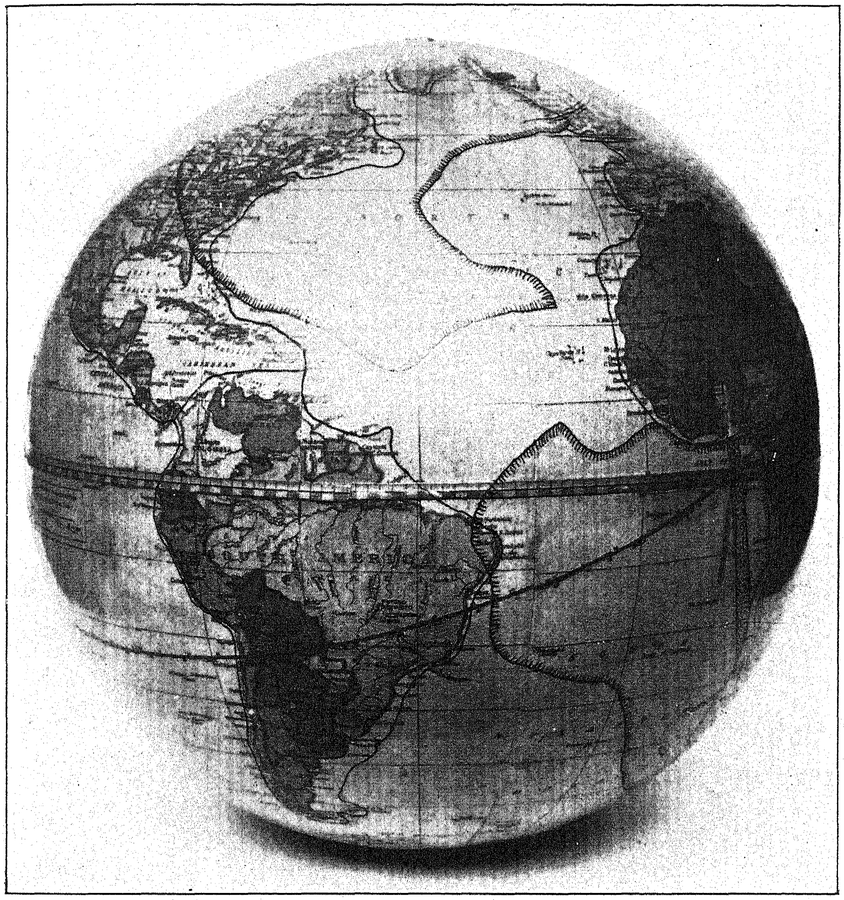
THE BREAKING UP AND MIGRATION OF PANGAEA AS ILLUSTRATED BY WEGENER IN "ORIGIN OF CONTINENTS AND OCEANS," 1925

Dotted areas, shallow seas; present-day outlines, rivers, latitude, and longitude only for purpose of identification



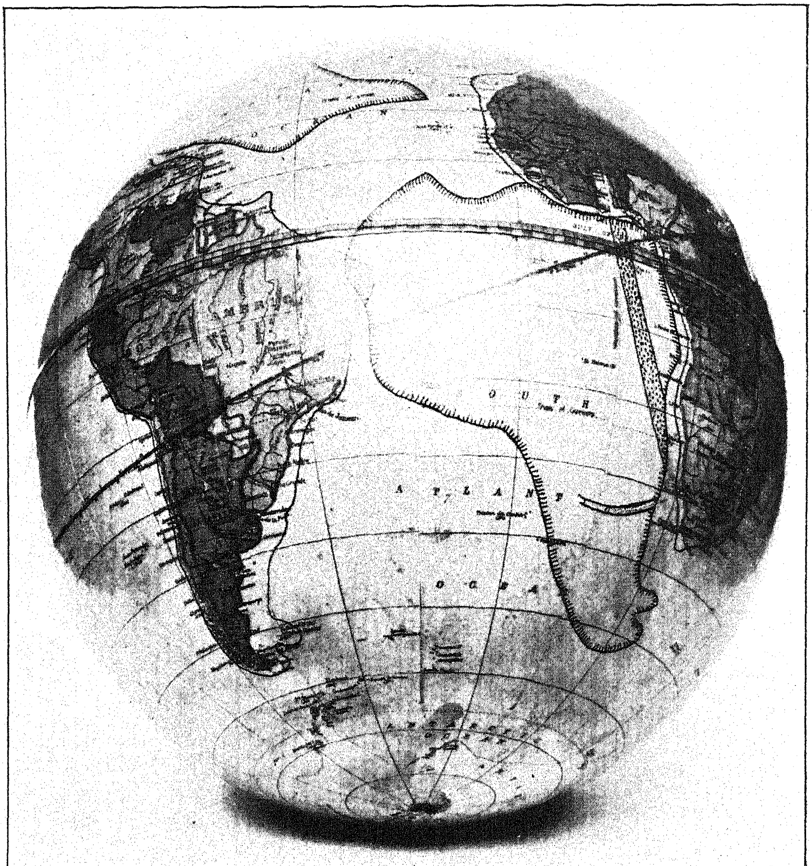
AN 8-INCH GEOGRAPHIC GLOBE OF THE EARTH WITH NORTH AMERICA PUSHED OVER AGAINST EURO-AFRICA, SO THAT NEWFOUNDLAND IS ADJACENT TO IRELAND

Note how Alaska is separated from Siberia, and Central America from South America. Compare with Figure 1



THE 8-INCH GLOBE, AS BEFORE, TO SHOW THE EQUATORIAL MISFIT

Compare with Figure 1



THE 8-INCH GLOBE, AS BEFORE, WITH SOUTH AMERICA SHOVED AGAINST AFRICA

Dotted area, Franciscan geosyncline. Note how South America is separated from Central America. Compare with Figure 1

the region of Bering Sea is known on the basis of fossils to have been of the nature of a shelf sea, thus permitting intermigrations of marine life between the Asiatic and American sides of the Pacific and into the Arctic as well. Not only this, but because of the shallow waters of Bering Sea there was made here from time to time after the Cambrian a land bridge which permitted the land floras and faunas to radiate from America to Asia or in the opposite direction.

Of the many criticisms made by Diener against the Wegener hypothesis, this was the only one that the latter answered, saying:

> Diener's objection, "Whosoever pushes North America on to Europe breaks its connection at the Behring Straits with the Asiatic continental block," is only met with in a Mercator's map but not on a globe, for the movement of North America consists essentially of rotation. At this point the blocks were never torn away from each other.

The plasteline method shows clearly that this can not be done without great distortion, and if the western connection is to be retained, as it must, then it leaves Newfoundland 600 miles southwest of Ireland. All through Wegener's book he insists that Newfoundland must be fitted against Ireland, yet when we do this we find that Diener is correct in saying that this tearing apart of Asia and America is fatal not only to the tectonic structures of Siberia and Alaska, but also to the very necessary migration routes for plants and animals.

Wegener's reply to all of this will be, of course, that if the nearly north-south trending Cordilleras of the western United States and the Appalachians had been straightened out, the required width would have been obtained to close up the gap between Alaska and Siberia. To which the writer counters that the mountains of Siberia and Alaska trend about east and west and the same is true for the northeastern end of the Appalachians in Newfoundland, so that we fail to gain the required land, but what is more significant is that the geology of Ireland and the Paleozoic sediments of Great Britain demand a wide land west and northwest of Ireland.

This and the criticisms still to follow show that our difficulties in present-day orthodox geology are by no means so unsurmountable as are those of Wegener's making.

HOW LONG WILL A COAST LINE RETAIN ITS INHERITED SHAPE?

As Lake says, undoubtedly it is the fitting of South America against Africa that makes the most general appeal. The correspondence in their coast lines has often been noticed—in fact, the philosopher, Francis Bacon, is said to have observed it in the sixteenth century—and vague suggestions have been made that they may have come apart from one another. This striking similarity of

coast line between Africa and Brazil has long vexed geologists and geographers, and a friend of the writer recently remarked that it must have been "made by Satan" for that very purpose.

Wegener tells us in the opening paragraph of his book that he came to this hypothesis in 1910 on noting—

the similarity of the shapes of the coast lines of Brazil and Africa (Figure 1). Not only does the great right-angled bend formed by the Brazilian coast at Cape San Roque find its exact counterpart in the reentrant angle of the African coast line near the Cameroons, but south of these two corresponding points every projection on the Brazilian side corresponds to a similarly shaped bay in the African, and, conversely, each indentation in the Brazilian coast has a complementary protuberance on the African. Experiment with a compass on a globe shows that their dimensions agree accurately.

Now let us see what questions these two fitted pieces of the jig-saw puzzle raise.

According to the displacement theory, hundreds of millions of years ago the South American plateau lay directly adjoining the African one, but in early Cretaceous time South America began to drift westward through the stiff basaltic material. Similarly, North America was close to Europe, and also began to drift westward in the Cretaceous, but, at least from Newfoundland and Ireland northward they still formed, with Greenland, one connected block until the end of Pliocene time.

We have seen that South America parted company with Africa in early Cretaceous time. Accepting the age of the earth as 1,500,000,000 years, this break occurred about 120,000,000 years ago. During this vast time the sea waves have been continuously pounding against Africa and Brazil and in many places rivers have been bringing into the ocean great amounts of eroded material, yet everywhere the geographic shore lines are said to have remained practically unchanged. It apparently makes no difference to Wegener how hard or how soft are the rocks of these shore lines, what are their geological structures that might aid or retard land or marine erosion, how often the strand lines have been elevated or depressed, and how far peneplanation has gone on during each period of continental stability. Furthermore, sea level in itself has not been constant, especially during the Pleistocene, when the lands were covered by millions of square miles of ice made from water subtracted out of the oceans. In the equatorial regions, this level fluctuated three times during the Pleistocene, and during each period of ice accumulation the sea level sank about 250 feet. Nowhere does Wegener discuss these matters, yet he wants us to believe that the original fracture lines have practically retained their original geographic shape during the 120,000,000 years. Is there a geologist anywhere who will subscribe to this startling assumption? From T. O. Bos-

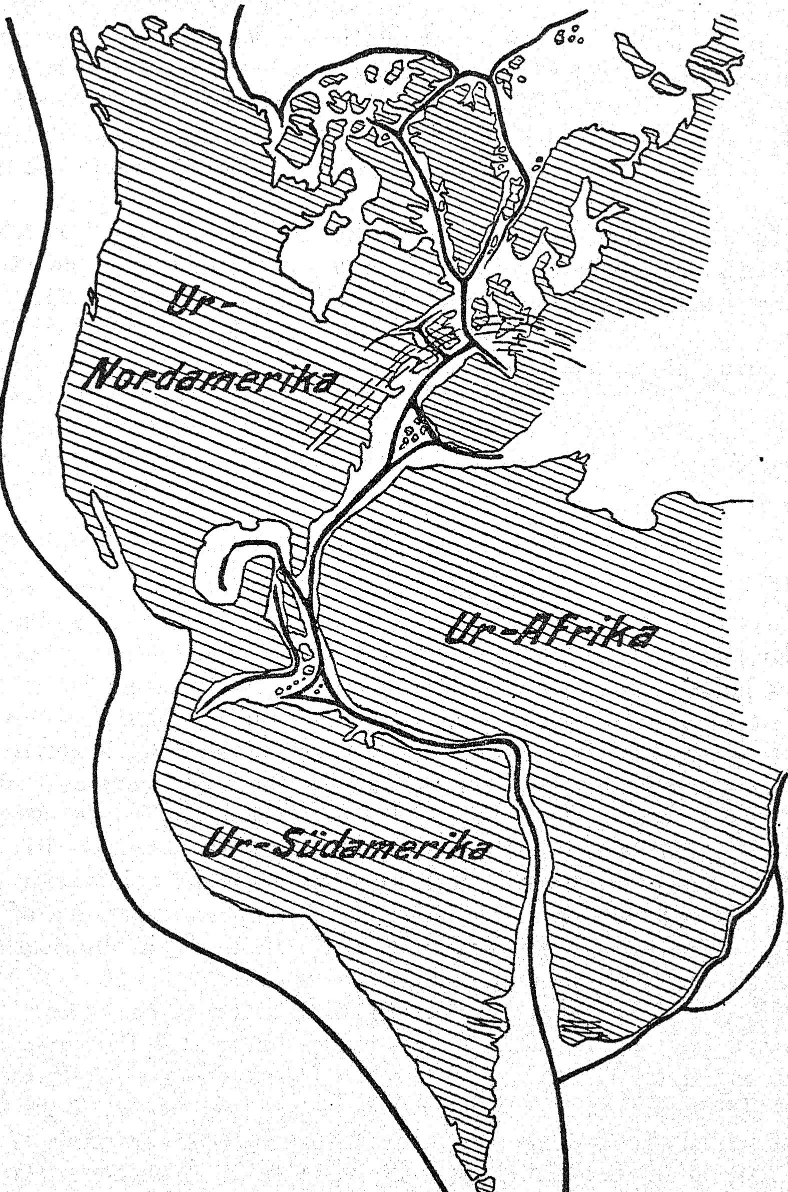


FIGURE 1.—Western Pangaea as illustrated in Behm's *Entwicklungsgeschichte*, 1924. Note how the fitting is done by elongation of the Americas, and how well the mountain strikes are made to agree on both sides of the Atlantic. Plates 2, 3, and 4

worth[6] we learn that there are in western Peru three prominent elevated marine terraces, the "tablazos" of the natives. These are "a monument to the efficacy of marine erosion," and the account of their making is one of the most interesting parts of the book. During the Pleistocene, he says, the Peruvian coast was "moved upward and downward hundreds of feet again and again. The sea advanced and retreated many times, cutting its cliffs into the land 10 miles or 20 miles on each occasion."

In other places Wegener tells us that the line of separation where the original continent split apart is not at the shore line but at the upper edge of the continental slope or the outer edge of the shelf seas, commonly placed at about 600 feet beneath the present sea level. In many places this not-well-ascertained line is very different from the shore line, but even so, what are the shelves if they are not the fills and cuts of the sea storms and currents? Are we to believe, with Wegener, that shore lines and shelf seas have remained constant in shape, position, and contour during 120,000,000 years?

WEGENER'S SEA MOVEMENTS AS PROOF OF POLAR WANDERING

In Chapter VIII of his book Wegener argues for a viscous earth, and says that if this is not true there could have been no crustal movement or polar wandering. But in regard to the latter hypothesis he says that polar wandering may actually be no more than crustal movement, or, in other words, that the axis of the earth may not change, but the crust only slips over the nucleus. However, he adds, "presumably both occur," namely, the poles move as well as the crust (pp. 121–122). To prove these conclusions he presents two greatly generalized maps showing transgressions and regressions of the seas over Pangaea, and says that when the pole wanders to the east it brings on in the Northern Hemisphere regression of the seas to the east and transgressions in the west, and in the Southern Hemisphere the water movements are reversed.

He selects Devonian to Permian time to prove this "law," for during these periods "the poles wandered rapidly." His map (his fig. 22) giving the transgressions and regressions over Pangaea for all Devonian and Lower Carboniferous time shows regression throughout South America, Central America, and the whole of the Appalachian geosyncline out to Newfoundland. Nothing is further from the truth for the Americas during Devonian time, since this is one of the periods of marked transgressions; during the Lower Carboniferous, North America also has wide transgression, but South America has almost complete regression. He presents a like map (his fig. 23) for all the time from Lower Carboniferous to upper Per-

[6] Geology of the Tertiary and Quaternary Periods of the Northwest Part of Peru, MacMillan, 1922.

mian. This shows that in northern North America there was regression during all of Carboniferous time, which is again just the reverse of the facts, for there were great transgressions during the Lower Carboniferous and Coal Measures, with marked regression during the Permian. In South America the map shows marked transgressions, but the facts are that here there were almost no seas in Lower Carboniferous time, marked ones in the Coal Measures, and small ones in the Permian.

The writer has elsewhere asked, "Of what use are paleogeographic maps that 'lump' together such vast amounts of geologic time?" They can prove nothing and certainly not polar wandering, for we know that North America had one very slowly progressing transgression during the Devonian, at least two more or less complete ones in Lower Carboniferous time, two in the Coal Measures, and one grand regression in the late Pennsylvanian and early Permian. No paleogeographic map is worth the paper on which it is printed unless it depicts the actual state of affairs for a limited geologic time, say several hundred thousand years, and not as Wegener does here, a number of transgressions and regressions that took place during 160,000,000 years. What Wegener should have done was to make at least 12 maps, and 9 for "Carboniferous time" (3 for each of its three periods), and then from these deduce his curves for each hemisphere.

SIMILARITIES ON THE TWO SIDES OF THE ATLANTIC OCEAN

It can be truthfully said that Wegener's hypothesis has its greatest support in the well-known geologic similarities on the two sides of the Atlantic, as shown in strikes and times of mountain making, in formational and faunal sequences, and in petrography (fig. 1). The main tectonic and faunal "connections" upon which he bases his theory are: (1) Between the Sierras of Argentina and the Cape Mountains of Africa; (2) between the Mediterranean and the Antillean region; (3) between the Armorican folds of Belgium and southern Great Britain and those of the Appalachians; (4) between the Caledonian ones and the Appalachians; (5) the pre-Cambrian similarities of northern lands; and (6) the comagmatic similarities between Euro-Africa and the Americas.

After making all discounts, it must be said that there still remain several geologic and faunal *similarities* on the two sides of the Atlantic, and chiefly in the north Atlantic. These have long been known, however, and have all had more or less satisfactory explanations on the basis of the present geography. But under Wegener's

hypothesis these slight similarities should be striking *identities*, and many of the marine faunas, for instance, should have, not 5 per cent of identical species, as is actually the case, but between 50 and 75 per cent, which is not true at all.

COMAGMATIC SIMILARITIES

The petrographic similarities have been treated fully by H. S. Washington,[7] who finds some between North America and Europe, but more between Africa and South America. About the latter region he says, however (pp. 344, 346):

> It thus seems to be evident that grave petrographical and chemical discrepancies exist between the rocks of the Guiana-Ceara coast and that of Guinea. . . . The balance of the petrographical evidence [between Brazil and Africa] may, then, be regarded as adverse to Wegener's hypothesis.

Washington's conclusions regarding North America and Europe are even less satisfactory.

TECTONIC SIMILARITIES

African Cape Mountains and Argentinian Sierras.—In the extreme south of Africa are the east-west-trending Zwarte-Berge or Cape Mountains, which are thrust to the north. In the east they go straight out to sea but in the west turn and strike northwest. It is plain that they have risen out of a typical geosyncline and accordingly must originally have been considerably longer than they are at present. Furthermore, there must have been a borderland to the south some hundreds of miles across, from which the main mass of sediments came. This broken-off (rias) ending of the Cape Mountains has always been explained by downfracturing of portions of South Africa both on the east and on the west, but this explanation Wegener rejects, because to him sial can not sink into sima. The chief geologist of Argentina, Doctor Keidel, has pointed out the structural, stratigraphic, and faunal similarities between the Cape Mountains and the Sierras of Buenos Aires, which in turn are continued into the pre-cordilleras of northwestern Argentina, furnishing Wegener with what he regards as striking evidence for

[7] H. S. Washington, Comagmatic Regions and the Wegener Hypothesis. Journ. Wash. Acad. Sci., vol. 13 (1923), pp. 339–347.

connections. Now let us see what these relations are, basing a synopsis of them upon Du Toit, Krenkel, and Keidel (Table I).[8]

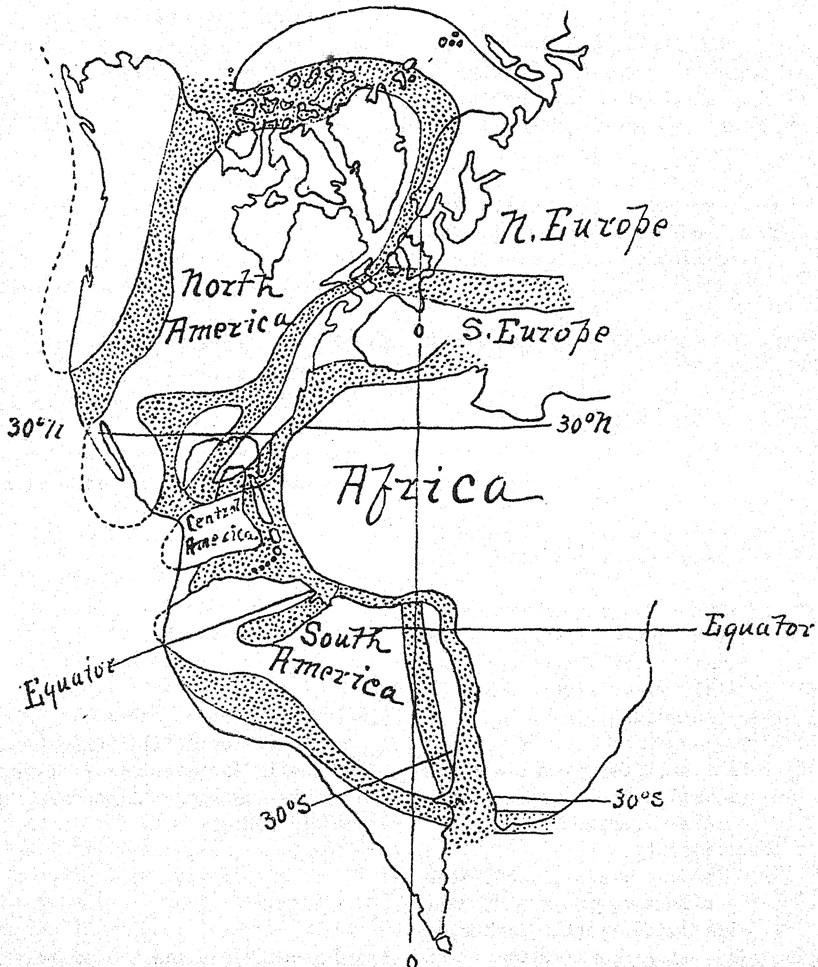


FIGURE 2.—Western Pangaea as drawn by Behm. Dotted areas indicate geosynclines after Schuchert; open areas, the regions where the continents do not fit

[8] A. L. Du Toit, The Geology of South Africa, 1926. E. Krenkel, Geologie Afrikas, vol. 1, in Geologie der Erde, 1925. H. Keidel, Ueber das Alter, die Verbreitung u. die gegenseitigen Beziehungen d. verschiedenen tektonischen Strukturen in den argentinischen Gebirgen, Internat. Geol. Congress, 12th session, 1913, Compte Rendu, pp. 671–687; La geología de las sierras de la Provincia de Buenos Aires y sus relaciones con las montañas de Sud África y los Andes, Rep. Argentina, Anales Minis. de Agricul., Sec. Geol., etc., vol. 2, No. 3 (1916), pp. 1–78 (not read). Since this paper was written there has appeared a book by Du Toit entitled "A Geological Comparison of South America with South Africa," published by the Carnegie Institution, 1927. Schuchert has discussed this book in The Continental Displacement Hypothesis as Viewed by Du Toit, Amer. Journ. Sci., September, 1928, pp. 266–274.

Table I.—*Geological relations between African Cape Mountains and Argentinian Sierras*

SOUTHERN AND WESTERN CAPE MOUNTAINS [Going up in sequence]	SIERRAS OF BUENOS AIRES
Pre-Cambrian systems. Formations marine, continental, and igneous. Primitive. Possibly Archeozoic. Proterozoic: Witwatersrand. Ventersdorp. Transvaal-Nama. Black Reef. Pretoria. Rooiberg. } A grand Proterozoic development.	Pre-Cambrian crystallines. Undifferentiated.
Mountain-making in late Proterozoic; long erosion.	Period of mountain-making.
Waterberg, age unknown.	Ordovician, extensive in sh., ls., ss., no known fossils, but such in pre-Cordilleras.
	Silurian sh. with *Arthrophycus harlani.* Well developed in northwest Argentina.
Cape system of clastics, 10,000 feet, usually regarded as Devonian. Land on North. 1. Table Mountain near-shore ss., sh., tillites, 5,000 feet: bivalves not diagnostic; age, Ordovician to Devonian. Disconformity.	
2. Bokkeveld, Lower Devonian, sh., ss., 2,500 feet; lower half marine with 130 species; upper half continental.	Lower Devonian ss., sh., with limited Bokkeveld fauna. Great development in northwest Argentina, but without tillites.
Disconformity. 3. Witteberg sh., ss., 2,500 feet; continental, probably Devonian or (?) Lower Carboniferous.	
Epeirogenic elevation, begun about Middle Devonian time, highest north of 30° S.	Possibly a time of marked orogeny in later Devonian.
Great hiatus.	Great hiatus.
Karroo system north of Cape Mountains, continental clastics, 15,000 feet, with terminal volcanics, 4,000 feet. Overlap on Cape Mountains.	
1. "Lower Permian" (Dwyka), lower sh., 700 feet; tillites, 1,000 feet; upper sh., 600 feet; no coals. *Mesosaurus, Noteosaurus.* In West, marine *Eurydesma* beds.	Permian tillites like Dwyka, interbedded with marine strata. No *Eurydesma.* *Mesosaurus* in Paraná, *Noteosaurus* in Brazil but none in Argentina.

TABLE I.—*Geological relations between African Cape Mountains and Argentinian Sierras*—Continued

2. "Middle Permian" (Ecca), sh., ss., 2,000 to 6,000 feet. Typical *Glossopteris* flora and rare appearance of "migrant" reptiles, *Archaeosuchus*, *Eccasaurus*.	Middle Permian with *Glossopteris* flora; no reptiles. Orogeny in Sierras and pre-Cordilleras.
3. Upper Permian (Lower Beaufort), ss., sh., 4,000 to 6,000 feet. Late *Glossopteris* flora, and greatest abundance of reptiles (70 species). *Pareiasaurus*, *Titanosuchus*, *Dicynodon*. *Propappus*, Therocephalia, *Lycosaurus*, *Endothiodon*.	Absent. [These Permian-Triassic interrelations between South Africa and South America are more fully discussed by Schuchert in a paper on the age of the Permian tillites, referred to in the footnote on p. 262 of this paper.]
4. Lower Triassic (Middle Beaufort), 1,000 feet. Zone of *Lystrosaurus* and *Procolophon*.	Absent.
5. Middle Triassic (Upper Beaufort), 2,000 feet. Zone of *Cynognathus*. *Erythrosuchus* related to *Scaphonyx*.	Absent.
6. Middle Triassic (Molteno), 2,000 feet.	Absent.
7. Upper Triassic (Stormberg) red beds, 1,600 feet, with dinosaurs; Cave ss., 800 feet, with dinosaurs.	Red beds, 2,900 feet, with *Scaphonyx* and *Erythrosuchus*.
8. Upper Triassic (Drakensberg) volcanics and dolerite intrusions, 4,000 feet north of Cape Mountains.	Plateau lavas in Brazil, 2,000 feet. Age uncertain, probably late Triassic.
Cape Mountains orogeny. Thrusting to north. Appears to have begun in late Beaufort (late Triassic) and continued periodically into Lower Cretaceous, resulting in high Cape Mountains.	Absent.
Lower Cretaceous (Uitenhage-Enon) marine overlap in southeast.	In pre-Cordilleras of northwest Argentina.
Unconformity.	
Upper Cretaceous (Pondoland) marine series, limited.	Folding of Andes.
Rifting and faulting in late Cenozoic time.	High epeirogenic elevation of Andes.

From this table we see that about all that is strikingly harmonious in the two continents is the orogeny at the close of the Proterozoic, the Lower Devonian (Bokkeveld) faunas, the Lower Permian tillites, and the *Glossopteris* floras; in Permian time, *Mesosaurus* and *Noteosaurus;* in late Triassic time, *Erythrosuchus* and *Scaphonyx*-like reptiles; and finally, in latest Triassic time, the plateau lavas. We gladly admit that these are striking similarities or identities, but after all they furnish slender evidence on which to base so important a conclusion as that Africa and Argentina were united to one another until Cretaceous time. Against this view are many more and greater dissimilarities, none of which is more striking than the almost total absence of the horde of African Permian reptiles and amphibia and the African Triassic dinosaurs in all of South America.[9] Furthermore, the writer's plasteline method of bringing South America against Africa leaves the Sierras 350 miles northwest of their supposed connections with the Cape Mountains (pl. 4).

On the other hand, it must be plain to anyone looking at western Pangaea that Wegener has greatly distorted and elongated the Americas, and chiefly in the Central American region (fig. 1). In this connection, Lake also says (1922) that when one moves the Americas rigidly and without distortion against Euro-Africa, then the Sierras of Argentina fail to meet the Cape Mountains by 1,200 miles.

Krenkel in his book on African geology has likewise studied Wegener's hypothesis in relation to the supposedly connecting geology and structures of eastern South America and western Africa, following out five lines of evidence. These are (1) the pre-Paleozoic grain of Brazil and West Africa, (2) the connections of the Cape Mountains with the Sierras of Buenos Aires, (3) the continental rocks thrown out by the volcanoes of Ascension, St. Helena, and Tristan d'Acunha, (4) the bathymetric nature of the ocean off West Africa, (5) the comagmatic relation of the igneous rocks on both sides of the Atlantic. In each instance he finds dissimilarities striking enough to cause him to decide against the displacement hypothesis. On the other hand, Du Toit (1926), because of the enumerations given on an earlier page, believes in a Pangaea, but in his book of 1927 he holds that South America at no time was united with Africa, but that they were always separated by something like 400 to 800 kilometers. This admission of the existence of a wide gap is, to the writer, of the greatest significance, and with

[9] This point and the more important of the known faunal and floral assemblages are discussed at length in a memoir prepared after this paper was written. It is entitled "A Review of the Late Paleozoic Formations and Faunas with Special Reference to the Ice Age of Middle Permian Time," Bull. Geol. Soc. Amer., vol. 38 (1928).

his orthodox views he sees the gap as having been never less than it is to-day.

Mediterranean-Antillean connections.—Now let us take up the postulated connections between Spain and the Atlas Mountains of northwestern Africa and Antillia. Wegener says (pp. 5–12) that the Atlas Mountains were folded "chiefly in the Oligocene, but had already commenced in the Cretaceous," but that these folds can not be found on the American side. It is true, nevertheless, that the Greater Antilles were also folded late in the Cretaceous and that they have been elevated epeirogenically at different times during the Cenozoic, and faulted on a most tremendous scale during the Pliocene. Accordingly it is curious to see that Wegener does not know these facts or is not willing to stretch them into his scheme. However, he easily gets around his difficulties by saying that the Americas were once closely adjacent to Euro-Africa, but that they have rifted and drifted apart before the Carboniferous. This, then, must have taken place in the Devonian or even earlier, and his most recent map for Upper Carboniferous time shows a north-south mediterranean some hundreds of miles in width, extending from South America north to about Long Island. The writer's reconstruction by the plasteline method, however, produces a good-sized North Atlantic Ocean (Poseidon) about 1,500 miles across either way (Pls. 2, 3). This conjectured mediterranean is, for Wegener, a saving stroke, and is, in any event, a feature that paleontologists have long been postulating to explain the origin of many south European Tethyan marine elements not only in the post-Ordovician faunas of the southern United States but also for the Silurian and Devonian of Brazil. These connections are seen again in the Permian and throughout Mesozoic time. But this mediterranean, the writer's Poseidon, in order to have been a normal sea for an abundance of life, and for migration possibilities, must have had a deep and wide oceanic connection with the Pacific across Central America, and this Wegener's map does not show. Now, however, that his attention has been directed to it, there will be no further difficulty about this, since with his pen he will draw in a Caribbean seaway uniting Poseidon and Tethys with the Pacific, solving this and other problems by the following strategy:

> But it is impossible to take up any strong view on this question so long as the size and outline of the Spanish block in the Devonian period are not known. * * * But as long as the displacement theory declares itself for these reasons unable to carry out the reconstruction of this region for the Devonian period, no one can tell whether the American Devonian will afford refutation or confirmation.

Caledonides.—Wegener is correct in connecting the Caledonian crustal trends of northwestern Europe with those of northern Newfoundland, but wrong in connecting them directly. At present it is less than 2,000 miles in a straight line from Ireland to Newfoundland,

and paleontologists need a distance something like this during Paleozoic times to explain the scattering faunal similarities of these lands. On the other hand, the stratigraphers of Great Britain insist on a high land to the northwest at least 500 miles across, or a low land at least 1,000 miles wide, to supply the great mass of detritals of Ordovician and Silurian times seen in these islands.

Everyone knows that the folding and thrusting of the Caledonian structures is intense. If, then, Newfoundland lay adjacent to Ireland, why is it that this exact time of orogeny is unknown in the former? And in any event, even if one fits the time of the Caledonian folding into that of the Devonian and early Permian time of Newfoundland, why does this intensity of the Caledonides decrease so quickly into the far simpler foldings of Newfoundland?

Hercynides.—In regard to the Hercynide structures, they can not be connected at all with the Appalachians; it is the Caledonides that connect with the latter.[10] What we see in northeastern North America connecting with the Hercynides are not the structural relations but the faunal ones of the North Atlantic (Poseidon). These connections are seen in the Lower Ordovician of southeastern Newfoundland, the Silurian of Arisaig, Nova Scotia, the Lower Devonian, and Lower Carboniferous (Windsor) of New Brunswick. The writer has long been explaining these similarities as due to the shelf seas along the south side of the New Brunswick geanticline, which was the borderland of the Appalachian-Caledonian seaway wherein the marine faunas migrated and evolved.

Regarding Wegener's reconstruction of the tectonic lines between northeastern North America and northwestern Europe, Lake says[11] that they fit very well, but that this results from taking great liberties with the earth's crust;

> he has pressed Newfoundland and Labrador strongly toward the northwest and has turned the former through an angle of about 30°. The westerly motion of Newfoundland may be admitted as consistent with the hypothesis; but if, in addition to moving the masses of sial, we are also allowed to mold them as we will, the coincidences that we deduce become evidence of imaginative powers, not of former realities.

Pre-Cambrian trends.—The pre-Cambrian connections of Holarctis across the North Atlantic are worthless for Wegener's purpose, because these structures were made during the first half of geologic

---

[10] E. B. Bailey (Nature, Nov. 5, 1927, p. 674) does actually make this connection, beginning with the Boston basin of Carboniferous formations and continuing southwest into the true Appalachians. But surely the Caledonides did not continue into Louisiana as shown on his map. An actual connection of the ends of the folds of the Boston basin with those of Belgium can not be demonstrated; this is far more readily done with the Caledonides of America and northwestern Europe. Furthermore, there is no demonstrated crossing, in Massachusetts or elsewhere in America, of the younger Hercynides over the older Caledonides. It is the theory of the matter that Bailey is discussing, while Wegener is saying that the several ends can be proved to have once been continuous.

[11] Philip Lake, Geo. Mag., vol. 59 (1922), p. 344.

time, and accordingly are of so vast an age and so little known that any advocate can read into them what he will. At the discussion before the British Association in 1922, Coleman pointed out that no dependence can be placed on them, since "the Archean is a universal formation," meaning that we have as yet not enough precise knowledge of these exceedingly ancient times to make long-range correlations.

According to Lake,[12] "In the Hebrides and northern Scotland, Wegener says, the strike of the ancient gneiss is from northeast to southwest; in Labrador it is from east to west." However, "the Survey Memoir on the Northwest Highlands gives the prevalent trend as west-northwest-east-southeast, or east-west."

THE FRANCISCAN GEOSYNCLINE AND AFRICAN GEOLOGY

We will now take up a structural element in the eastern part of South America that is unknown to Wegener, because it has never been presented in generalized form. In its revelation of how little the geology of Brazil is related to that of Africa, it deals, however, a crushing blow to the displacement hypothesis.

Some years ago, in a study of the seaways of South America, the writer was surprised to find that there is a slightly northeast-southwest trending geosyncline in eastern Brazil. This trough he has called the Franciscan geosyncline, taking the name from the large San Francisco River that lies in a great length of it. Evans's map of the tectonic lines of South America, reproduced by Wegener (p. 50), correctly shows the trend-lines for this trough, but at the northeast he has southeast-northwest strikes, which must be of pre-Cambrian foldings; accordingly, the trough passed over this old ground and grain.

This Franciscan geosyncline of eastern Brazil is a long and narrow marine trough present at least since the early Silurian. It was not folded into mountains until middle Permian time, and apparently then on the west and northwest. Later on, the area of the geosyncline was also invaded by fresh-water strata of late Triassic age, and finally, during latest Triassic and earliest Jurassic time, an area at least 300,000 square miles in extent between the Amazon, Paraná, and La Plata Rivers was covered by plateau lavas averaging about 1,000 feet in thickness. These are overlain by fresh-water sandstones thought to be of Cretaceous age. None of these post-Permian formations are folded, though they are more or less normally faulted.

The Paleozoic sediments are essentially sandstones and shales having a united thickness of less than 6,000 feet, though there may also be present strata older than the Silurian. The Silurian and Devonian are marine deposits, about 2,000 feet thick, while those of the

[12] Op. cit., p. 343.

Permian, 2,400 to 3,400 feet thick, are in the main continental, although marine and brackish water zones occur almost throughout the whole of them. All the Paleozoic detritals appear to have come from the east; to the west they are buried under the plateau lavas.

The formations of the Franciscan trough have not heretofore been interpreted as of a geosyncline, but Branner's map of 1919, taken together with the nature of the deposits, and the position east of a high borderland during the Paleozoic, with the Amazon shield on the west, show that we have here all of the structural elements of a geosyncline. In a general way the center of this trough may be said to lie east of Maranhão, and somewhat west of São Paulo, with the axis trending slightly southwest, and finally it extends along the coast to Rio Grande do Sul.

Since Wegener holds that South America all through the Paleozoic and most of the Mesozoic lay closely adjacent to Africa, the Franciscan geosyncline must find its continuation northeastward through western Nigeria. Now let us see what is known of the general geology of western Africa, depending upon Lemoine, Chudeau, and Krenkel.[13] As one proceeds from the Mediterranean southward across West Africa into the Gulf of Guinea, the dated geology becomes more and more obscure, and this is mainly because one passes from younger rocks and the depths of ancient Tethys toward older ones and finally up against the pre-Cambrian shield of central Africa. This shield also extends widely through southern West Africa west to Liberia and Sierra Leone. In a general way, we can say that the Paleozoic seas of the north transgressed southward upon this very ancient nucleus of Africa, with the southernmost shore extending from about western Liberia, thence striking northeast to north of Nigeria, and so on into the southern Sahara, where it is lost. It is well known that there are much folded and metamorphosed schists south of this old coast, and especially in the Gold Coast state; these have sometimes been referred to the early and middle Paleozoic, but Krenkel points out that they are more probably of Proterozoic age. Accordingly we see that the structure and the dated sediments of the Franciscan geosyncline of Brazil abut directly against the old nucleus of Africa, and no continuation at all occurs of this South American trough. On the other hand, we gladly grant that the Tethyan overlaps upon Africa, having east and west strikes, and with faunas of the Atlantic-Mediterranean realm, strikes into the Amazon valley, but all paleontologists who have studied these Silurian, Devonian, and Pennsylvanian faunas of Brazil have pointed out

[13] The best general statement, with maps, is by Paul Lemoine: Afrique occidentale. Handbuch d. regionalen Geologie, vol. 7, pt. 6A, 1913, pp. 1–88. A later work treating of the tectonics is by R. Chudeau: Recherches sur la tectonique de l'Afrique occidentale, Bull. Soc. Géol. de France (4), vol. 18, 1918, pp. 59–87. E. Krenkel, Geologie Afrikas, vol. 1, in Geologie der Erde, 1925. The detail of the geology of West Africa is to appear in the second volume; all that we have here is a much generalized account on pp. 46–47.

that they agree better, though distantly, with those of the Mississippi valley than they do with those of Africa. As paleontologists, we can explain these faunal similarities between Brazil, northwestern Africa, and the Mississippi Valley far more easily by long distance migration routes along shelf seas bordering a land bridge across the Atlantic, than by the close union of these lands.

In western Africa there are, at least, dated Middle Ordovician mudstones, with *Climacograptus*, *Diplograptus palmeus*, and *D. insectifrons*, probably a long Silurian sequence of mudstones from which are recorded *Monograptus priodon*, *M. lobiferus*, and *Arthrophycus*, followed by a long sequence of Lower, Middle, and Upper Devonian sandstones with an abundance of identified fossils. Then there is a long hiatus followed by lower (Dinantian) and upper Pennsylvanian (Moscovian) faunas, succeeded by Permian continental deposits with tillites. The next overlap of Tethys was in Cretaceous time, and it was a widespread one, followed by others of the Cenozoic.

The pre-Cambrian formations of western Africa have tectonic lines—the Africanides—that in general trend northeast 45° to 75°, but there are also north-south strikes. The next time of folding—a striking one—came during the later Silurian. These are the Saharides, and it is now seen that they have no direct connection with the Caledonides of northwestern Europe, as is usually assumed. The trends of the Saharides are more or less like those of the Africanides, but the two maps of Chudeau give them in the south as trending northeast and then turning and striking east-west and folded on the southeast and south. Then followed, much farther north, the late Pennsylvanian orogeny—the Hercynides—with the trend-lines striking in a totally different direction, namely, from northwest to southeast. Finally, in the Eocene-Oligocene came the folding of the Atlas Mountains—the Alpinides of extreme northwest Africa—with southwest-northeast strikes.

In Brazil there is no orogeny of Silurian or Devonian time at all, some but not markedly strong folding in the Permian, and none at all in Cenozoic time. There may, however, have been a time of decided folding in the early Paleozoic, either at the close of the Ordovician or earlier.

These facts show that there are but few geological connections between Brazil and western Africa, and there should be many if they once were closely adjacent. Each area has its own independent geologic development, unlike that of the other, indicating clearly that Brazil and northwestern Africa, since at least the Silurian, have been independent and far separated. In this connection, we must recall what Suess said in his famous book, The Face of the Earth:[14]

[14] E. Suess, The Face of the Earth, vol. 1, 1904 (German ed., 1885), p. 537.

South America presents in a higher degree than any other part of the world all the features of a homogeneous structure.

On the other hand, the writer is well aware that recently J. W. Gregory has postulated a north-south trending seaway for Middle Cretaceous (Albian) time—his Angola Gulf (he does not call it a geosyncline)—extending from Tripoli south across the Sahara and so on through western Cameroons and thence along the west coast of Africa to Cape Frio. He says [15] that it

was not formed till middle Albian times, and the configuration of the Brazilio-Ethiopian continent was essentially the same throughout the upper Albian.

NEWFOUNDLAND AND IRELAND [16]

In many places in Wegener's book we find indirect statements to the effect that Newfoundland was separated from Ireland during Pleistocene time, and direct passages to this effect are found on pages 12, 55, 60, 110, 111, 117, and 172. We get the best idea of this connection in the following statement (p. 12):

Similarly, North America was close to Europe; and at least from Newfoundland and Ireland northward, they formed with Greenland one connected block.

Finally, he states (p. 110):

The separation may have taken place at the period of maximum glaciation, or, just as possibly, shortly before. In any case, the distance between the blocks was not of any considerable importance when the glaciation was at its maximum; on the other hand, the blocks must have been separated considerably by the time of the last glaciation.

This connection is also illustrated in his map (p. 111) entitled "Reconstruction of the Continental Blocks for the Great Ice Age." Since, therefore, the separation of Newfoundland from Ireland took place during the Pleistocene, the geology of Newfoundland and Ireland should be alike for all of geological time. Now let us see what are the actual relations, as set down briefly in Table II in opposing columns for easy comparison.

These facts show unmistakably that Newfoundland was never a part of Ireland, and that each land belongs to a widely differing geological province. Furthermore, the faunas of the two countries are so different that they must ever since Cambrian time have been of distinct faunal provinces, and, judged by those of the present must have been separated from each other by several thousand miles of migration routes. Their faunal similarities and dissimilarities can

[15] J. W. Gregory, Supplementary Note on the Geology of Benguella in Relation to Its Cephalopods and the History of the South Atlantic, Trans. Roy. Soc. Edinburgh, vol. 53 (1922), pp. 161–163.

[16] For Ireland, see the volume on the British Isles in Handbuch der regionalen Geologie, vol. 3, pt. 1, 1917; Stanford's Atlas of Great Britain and Ireland, 1907; Jukes-Browne, Building of the British Isles, 1911.

be explained only by long migration routes, and the strongest similarities are found only among the graptolites (floaters), corals (larvæ long in development while floating), and trilobites (good swimmers). Nor do the times of orogeny agree, and while volcanic activity was marked in Great Britain during the Ordovician and Silurian, almost nothing of the kind occurred in Newfoundland.

Evans, in his introduction to the English edition of Wegener's book,[17] makes the following astonishing statement:

> The succession of the sedimentary rocks in areas now separated by thousands of miles of sea shows remarkable resemblances that can only be reasonably explained if these sediments were laid down in close proximity to one another and under practically identical conditions.

The accompanying presentation of the geology of Ireland and Newfoundland shows, however, that there is very little in common between these two countries in their stratigraphic sequence, facies conditions, volcanic activity, orogeny, or marine faunas. Why is this? Because the St. Lawrence geosyncline and the New Brunswick geanticline once extended across the Atlantic (with something like its present dimensions) to Scotland and thence into Norway and Sweden. Holtedahl has brought this out a number of times, and we paleontologists must in this case, and in others as well, have the long migration routes to explain the slight relationship between the faunas of northeastern North America and northwestern Europe.

---

[17] A. Wegener, op. cit., pp. vii–viii.

TABLE II.—*Geological relations between Newfoundland and Ireland*

NEWFOUNDLAND	IRELAND
Nature of Paleozoic sediments and strike of St. Lawrence geosyncline call for a land of great area on northwest. This trough does not strike into Ireland, but does go through northwest Scotland.	Nature of Paleozoic sediments and strike of Caledonian geosyncline call for a land of great area on west and northwest. A view held by all since its presentation by Hull. This land can not be Newfoundland with its separate marine history.
The New Brunswick east-west geanticline separates the northern St. Lawrence geosyncline from the southern Acadian one.	Absent.
Acadian geosyncline has from time to time slight faunal connections with Great Britain.	Absent, unless connections are made with the Armorican geosyncline; faunal similarities then slight.
Strike of St. Lawrence geosyncline slightly northeast.	Strike of Caledonides northeast, but considerably less than in Newfoundland.
Strike of Appalachides northeast.	Strike of Hercynides east.
Archeozoic of very wide surficial distribution, mainly granites.	Archeozoic not definitely known.
Anorthosites the characteristic igneous rocks.	None in Great Britain.
Proterozoic detritals of southeast in northeast-southwest troughs.	Proterozoic in Dalradian detritals that connect with Torridonian of Scotland.
Lower Cambrian in two geosynclines separated by New Brunswick geanticline. St. Lawrence trough has Lower and Upper Cambrian. Acadian trough has Lower and Middle Cambrian, with European faunal similarities.	Cambrian. (?) Limited, poorly understood, restricted on southeast. No diagnostic fossils, age not proved. No comparisons possible with Newfoundland.
Middle Cambrian in Acadian trough. Decided faunal connections with northwest Europe.	Unknown.
Upper Cambrian-Ozarkian ls. in both basins. Little understood.	Unknown.
Lower Ordovician ls. in great development in St. Lawrence geosyncline. Faunal connections with northwest Scotland. Detrital facies of Acadian geosyncline in great development, with Welsh faunal similarities.	Correlates with Tremadoc and Arenig clastics, but both are unknown in Ireland.
Middle Ordovician (Chazy) ls. in marked development in St. Lawrence trough. None in Acadian trough.	Llandeilo in southeast, detritals and volcanics. No American faunal connections other than graptolites.
Tectonic movement. (?) Block faulting.	
Middle Ordovician (Black River-Trenton) in vast detrital development in northwest. No volcanics. Fauna limited.	Bala of southeast and elsewhere in vast development of detritals and volcanics. Ends in 9,000 feet of continental deposits. No American faunal connections other than graptolites.

TABLE II.—*Geological relations between Newfoundland and Ireland*—Continued

Upper Ordovician (Richmond) ls. with rich fauna in St. Lawrence geosyncline.	May be in Bala series, but if so faunas are wholly unrelated to those of America.
Lower-middle Silurian, probably well developed in near-shore facies, restricted to St. Lawrence geosyncline, but faunally little known. Anticosti farther west shows limited Swedish and English faunal connections.	Entire Silurian appears to be present, thick, in near-shore facies, becoming more and more normally marine, and connects directly with Silurian of Great Britain faunally and stratigraphically. Volcanics present. Faunas not closely related to those of Newfoundland.
Upper Silurian unknown.	
No orogenic movements or volcanic activity.	Great orogenic movement, making of Caledonides at close of Silurian.
Devonian absent. Land. Volcanic activity in Lower Devonian.	Devonian in marked Old Red Sandstone facies with possibly some marine, 3,000–10,000 feet and possibly 20,000 feet, with volcanic materials.
Making of Acadian Mountains throughout northeast North America in late Devonian.	No orogeny.
Absent. Land.	Lower Carboniferous (Avonian) in massive ls., the chief strata of Ireland. Rich in fossils with slight American similarities.
Late lower Carboniferous (Windsor) detritals, dolomites, gypsum, and limited marine faunas which connect with southern England and Belgium.	Late lower Carboniferous with volcanics. Faunas almost unknown, but well known in southwest England and Belgium.
Absent.	Early upper Carboniferous, marine.
Coal Measures series of continental type well developed in Acadian trough. Orogeny periodic.	Coal Measures series of continental type once widely present. Orogeny periodic.
Absent. Land.	Marine and continental Permian but little developed in Ulster. Widely present in Great Britain and Germany.
Marked orogeny of early Permian time but only in southern Appalachians.	Great Permian orogeny but apparently much later than in America.
Land and erosion.	Early (red continental) and late Triassic (mostly continental) and marine Lias and Upper Cretaceous, all limited to northeast.
Latest Cretaceous with epeirogenic elevation.	(?)
Absent.	Eocene plateau lavas.
Pliocene epeirogenic elevation.	(?)
Pleistocene ice sheets.	Pleistocene ice sheets.

Wegener discusses at some length the structural relations of northwestern Europe and northeastern North America and makes out to his own satisfaction a clear case that the two sides were once closely adjacent, that they broke apart during Pleistocene time, and since have drifted apart some thousands of miles. How well the edges of the two continents fit together is already shown for Newfoundland and Ireland. Then we get this characteristic Wegenerian conclusion (pp. 55–56):

> The correspondences of the Atlantic coasts, namely, the folding of the Cape Mountains and of the Sierras of Buenos Aires as well as the correspondence between the eruptive rocks, sediments, and strike-lines in the great gneissic plateaus of Brazil and Africa, the Armorican, Caledonian, and Algonkian systems of folding, and the Pleistocene terminal moraines, in their sum total, . . . yield a proof, which is difficult to shake, of the validity of our supposition that the Atlantic must be considered as an expanded rift. . . . It is just as if we put together the pieces of a torn newspaper by their ragged edges and then ascertained if the lines of print ran evenly across. If they do, obviously there is no course but to conclude that the pieces were once actually attached in this way. If but a single line rendered a control possible, we should have already shown the great possibility of the correctness of our combination. But if we have *n* rows, then this probability is raised to the *n*th power. It is not a waste of time to make clear what this implies. We can assume, merely on the basis of our first "line," the folding of the Cape Mountains and the Sierras of Buenos Aires, that the chances are 10 to 1 that the displacement theory is correct. Since there are at least six such independent controls, 10^6, or a million to one, could be laid that our assumptions are correct.

Figures used in this way, however, can prove nothing, and his conclusion from them that he is correct 10^6 is, of course, absurd.

FAUNAL AND FLORAL CONNECTIONS

We have already stated that Wegener began to think about his continental displacement theory because of the present geographic similarities of the eastern coast of Brazil when compared with the western coast of Africa. This led to conviction on his part, once he became aware of the "paleontological evidence," that these lands had formerly been united. This evidence—which I may claim to know fairly well—lies in the close similarities between the *Glossopteris* flora of middle Permian time on both sides of the southern Atlantic, together with the presence of the marine reptiles *Mesosaurus* and *Noteosaurus* in both South America and Africa. To this can be added the further facts that the Lower Devonian (Bokkeveld) marine fauna of South Africa extended into Argentina and southern Brazil, and that the *Trigonia*-ammonite faunas of late Jurassic and early Cretaceous times of northwestern Argentina and eastern Africa were of one marine province. One might add to this favorable evidence even more, but, after all, the identities and similarities are not plentiful; on the contrary, they are very meager and yet they

show clearly enough that we are treating here of one marine austral realm (see Table I). If the migration routes had been short, say within some hundreds of miles, which would be the case if Africa and South America had been united, these marine faunas would have a great many species in common, probably more than 50 per cent of identities, but their relationships are in reality so distant as to indicate plainly that the dispersion has been along thousands of miles of coast lines and during long periods of time, causing most of the elements to evolve *en route* not only into other species and genera, but even into different families.

Any paleontologist who reads carefully pages 98 to 106 of Wegener's book, dealing with the distribution of the Coal Measures and *Glossopteris* floras of Permo-Carboniferous time, will see not only the nimbleness and versatility of his mind, but as well how very easy it is for him to make all facts fit his hypothesis. Why is this? Because he generalizes from the generalizations of others, and compares unlike things, regarding the correlation of formations by geologists as dealing with "relatively trifling differences of time" (p. 98). In these pages he is explaining his views of the climate of "Permo-Carboniferous time," and, in doing so, shoves the south pole to a place off the southeast coast of Africa, arranging the equator accordingly.[18] Finally, to make it easy for all of us to get his views, he pictures them on a single diagram [19] entitled "Evidences of Climate in the Permo-Carboniferous." In this single diagram, he undertakes to represent events that took place during a lapse of something like 50 million years, makes the flora of the tropical Coal Measures fit the "polar" *Glossopteris* flora of the much younger Permian, and in order that the latter may be truly polar assumes that it was treeless,[20] says that Antarctis then was adjacent to southeastern Africa with the south pole at the edge of it, and on this basis arranges the climatic belts around it (fig. 3)!

The *Glossopteris* land flora occurs not only in India, Africa, and very widely in South America, but also in the Falklands, Antarctica, and widely in Australia.[21] Paleobotanists are not all agreed as to

---

[18] Gerth, who has studied the corals of the Permian of Timor in the Dutch East Indies, says that they are of warm waters, and this conclusion is also borne out by the associated species, which together make up the largest known Permian fauna, of about 600 species. Such a fauna could not have lived beyond 30° south latitude, and on Wegener's projection of the Permian it would have occurred at about 45° south latitude. As Gerth says, the Timor Permian fauna alone proves that the South Pole could not have been where Wegener places it. See H. Gerth, Die Korallenfauna des Perm von Timor und die Permische Vereisung, Leid. Geol. Meded., 1926, pp. 7–14.

[19] A. Wegener, op. cit., p. 100.

[20] Gothan in 1911 pointed out that the fossil woods of Australia and Falkland have annual rings.

[21] For an excellent account of the climatic and geographic dispersion of this flora see David White, Permo-Carboniferous Climatic Changes in South America, Journ. Geology, vol. 15 (1907), pp. 615–633. The Permian problems have recently been discussed by Schuchert at length in his memoir of 1928, referred to on an earlier page.

how this flora was dispersed. Some hold that it traveled across a land bridge from Brazil to Africa and thence to India, and others postulate a bridge from South America to Antarctica and from here another one to Australia. It is not even known where this flora originated (some paleobotanists think in Antarctis or Australia), but if it arose in South America and went over a land bridge to Antarctis, the rest of the distribution might have been by way of oceanic currents, just as South and Central American and Asiatic dicotyledons have in Cenozoic time reached the Hawaiian Islands, which have always been isolated volcanic masses. On the other hand, David White points out that the younger Permian flora is clearly, through

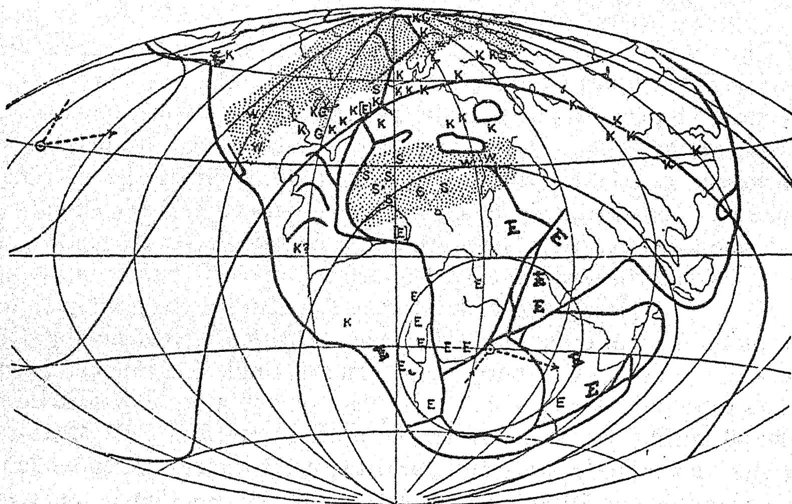


FIGURE 3.—Pangaea of Carboniferous time as illustrated by Köppen and Wegener in *Die Klimate der geologischen Vorzeit*, 1924. E, glacial evidence (introduced in part by Schuchert); K, coals; S, salt; G, gypsum; W and dotted areas, deserts

climatic rigors, a highly modified outgrowth of the world-wide Coal Measures flora, and so it may well be that it arose in several places and through migration and combination with the hold-overs of the older floras became the well-known *Glossopteris* flora.

Lake[22] has gone at length into the distribution of the *Glossopteris* flora, and makes the following points: The *Glossopteris* flora is found also in Kashmir, northwestern Afghanistan, and northeastern Persia, Tonquin, northern Russia, and Siberia. In Russia it is accompanied by South African reptiles and fresh-water shells.

Wegener's explanation has not by any means simplified the problem of the distribution of the *Glossopteris* flora and fauna.

Lake then considers the distribution of the Permian tillites and says:

[22] Philip Lake, Nature, Feb. 17, 1923, p. 227.

Even if we admit movement of the pole [and Wegener moves the south pole 2,500 miles from its present position], on the most favorable supposition the ice must have spread much farther toward the equator than the ice sheets of the Pleistocene Glacial period ever did.

There are Permian tillites in the Salt Range of India, in Afghanistan (on Wegener's map, p. 100, this would be within 30 degrees of his assumed equator), in northwestern Africa, at Boston (on the same map this would be on the equator), and arctic Alaska.

Coleman is to-day our best informed authority on the distribution of glacial climates, and has seen the "Permo-Carboniferous" tillites in many lands. He says that on the basis of Wegener's Pangaea, and placing the South Pole in southeastern Africa—

the glaciated areas would be far inland and out of reach of the moisture-laden winds necessary to deposit snow. They would be arid regions without permanent snow fields, like the interior of Asia, which was not glaciated in the Pleistocene though one of the coldest regions of the world. It is evident, then, that the drift of the continents and the shift of the poles do not help us to account for the Permo-Carboniferous glaciation.[23]

And finally this:

It may be confidently stated that a careful study of the two greatest periods of glaciation known to geology gives no support to the theory of the drift of continents and the wandering of the poles.

Wegener relies much on the present distribution of the earthworms as proving his theory for western Pangaea. He says (pp. 78–79):

The present distribution of earthworms offers particularly unobjectionable evidence of the former Atlantic land connections, because usually the sea is an insurmountable obstacle to these animals. A singularly large number of threads of affinity are spun by them across the Atlantic Ocean in the various latitudes.

We may add here that there are several other equally remarkable "threads of affinity" that he might have used, namely, the present distribution of the Unionidae, land snails, macrouran crustaceans, spiders, lung fishes, caecilians, etc. All of these distributions are, however, at least as easily explained by the presence of a bridge from Brazil to Africa—the commonly accepted explanation—of which Wegener will have none.[24] On the other hand, it must not be forgotten that all of these stocks are ancient, some going back at least to the Lower Cretaceous or Jurassic and the rest to different periods in the Paleozoic; the lung fishes date from the Devonian and the earthworms may be even more ancient. We are here dealing with the organic radiation of a vast amount of geologic time, going back several hundred million years. What a vista is thus opened up of the possibilities in biogeographic distribution, and how variously it may

---

[23] A. P. Coleman, Permo-Carboniferous Glaciation and the Wegener Hypothesis, Nature, Apr. 25, 1925, p. 602.

[24] These faunal connections are fully discussed by Hermann von Ihering in his Geschichte des Atlantischen Ozeans, Gustav Fischer, 1927.

all have come about! We appear, therefore, to be able to say that with so much time available we might even do away with the middle Atlantic land bridge and explain the distribution of all land life on the basis of radial dispersion from Holarctis and Antarctis.

The writer has long been a believer in a land bridge—a far narrower one, however, than usually shown on paleogeographic maps—all through the Paleozoic and Mesozoic across the Atlantic from Brazil to Africa. This bridge appears to him necessary to explain the peculiar distribution of the various Paleozoic and Mesozoic marine faunas of northern Brazil, the Andean geosyncline, Central America, and the southern part of the United States, on the one side, and those of southern South America, south and east Africa, and India, on the other. But this western Gondwana land bridge appears even more necessary to explain the similarities of the land floras and faunas, and yet all biogeographers admit the great possibilities of radial dispersion from Holarctis. Such migration routes have been possible ever since the beginning of the Cambrian, but have been made locally and chronologically inoperative through periodically appearing mountain ranges, desert climates over vast areas, and variations in the spread of the great mediterranean Tethys and other oceans.

Grant the biogeographer Holarctis, a land bridge from northern Africa to Brazil, another from South America to Antarctis (it almost exists to-day), still another from this polar land to Australia and from the latter across the Arafura Sea to Borneo and Sumatra and so on to Asia, plus the accepted means of dispersal along shelf seas and by wind and water currents and migratory birds, and he has all the possibilities needed to explain the life dispersion of the land and ocean realms throughout geological time on the basis of the present arrangements of the continents. With these means he can also explain life dispersion far more easily than by way of Wegener's Pangaea; this hypothetic land should have made for easy dispersion and therefore for cosmopolitan floras and faunas, and that is just what the world has very rarely seen and does not have to-day.

CONCLUDING REMARKS

The previous account has again and again shown that the rump mountain ranges on the two sides of the Atlantic are not at all as closely related in position, structure, and history as Wegener makes them out to be, and the same is equally true for the fossil marine faunas. The writer does not wish to say that there are no geological and paleontological similarities at all on the two sides of the Atlantic, for there are many faunal ones easily seen and there are structural ones as well, which were pointed out long before Wegener's time. But the whole trouble in Wegener's hypothesis and in his

methods is, as we have said, that he generalizes too easily from other generalizations, and that he pays little or no attention to historical geology or to the time of the making of the structural and biologic phenomena discussed. It is not, as he says, that the detailed worker can not see the forest because of the many different trees, or that the paleontologists need a geophysicist to show them the road on which they should travel. Facts are facts, and it is from facts that we make our generalizations, from the little to the great, and it is wrong for a stranger to the facts he handles to generalize from them to other generalizations.

It will be interesting to see what other critics of the displacement hypothesis have concluded. Carl Diener,[25] the learned paleontologist of Vienna, says that at first sight the hypothesis appears to have much of value in it, but on close analysis it turns out to be

> but a playing with actual possibilities. * * * It fails in fundamental facts of a positive nature, and a whole series of paleogeographic facts can not be brought into harmony with it.

Reid comments: "The elasticity of the Wegener hypothesis is evident." And Lake,[26] who has gone into it at length, states:

> Whatever Wegener's own attitude may have been originally, in his book he is not seeking truth; he is advocating a cause, and is blind to every fact and argument that tells against it. Much of his evidence is superficial. Nevertheless, he is a skillful advocate and presents an interesting case.

What is valuable in the hypothesis is this:

> He has performed a valuable service by drawing attention to the fact that land masses may have moved relatively to one another. He has not proved that they actually have moved, and still less has he shown that they have moved in the way he imagines. He has suggested much, he has proved nothing.

Berry [27] says in 1922:

> I can see no record of such a former union [of South America and Africa] in anything that we know of the stratigraphy, structure, faunas, or floras. * * * I much prefer the older hypothesis of land bridges and subsidence.

In regard to the geological climates, as set forth by Köppen and Wegener, Berry says:[28]

> Neither has the slightest idea of the bearing of fossil faunas or floras on the problems which they set out to explain, and therefore wherever their conclusions lead they explain something which never existed.

Arthur Keith in his presidential address, entitled "Structural Symmetry in North America,"[29] finds that the mountains in North

---

[25] Op. cit., p. 342.
[26] Geol. Mag., vol. 59 (1922), pp. 338, 340, 346.
[27] E. W. Berry, Outlines of South American Geology, Pan-Amer. Geol., vol. 37 (1922), pp. 187–216.
[28] E. W. Berry, The Term Oligocene, Amer. Journ. Sci. (5), vol. 13 (1927), p. 256.
[29] Bull. Geol. Soc. Amer., vol. 39 (1928), pp. 321–386.

America are built in the main by the same fundamental process, namely, subsidence of the oceanic areas. This sinking of the oceans brings on subcrustal flowage toward and under the continents, elevating them most along their margins, and at the same time pushing them and the geosynclinal areas inward against the neutral and shield areas of the interior land.

The repetition from age to age of the same sort of structures at any given tract on the continent is a fact of absolutely the highest importance. It indicates not only a persistent arrangement of cause and effect, but also a permanence of form and environment, which make of North America an extremely well-defined unit having a definite system of structural laws and responding to repeated thrusts from the direction of each of the adjoining oceans. In this history I can see only an individuality of the continent, its unity, and also its permanence of environment, and I see nothing of the haphazard arrangement which must have followed the random course of a continent floating like a waif on a sea of sial (p. 372).

Discussing the Wegener and other similar hypotheses, Keith concludes (p. 384):

I am convinced that it is reasonable to accept the theory of thrust against the continent [North America] from all of the surrounding oceans, and also the doctrine that the continental shape and size have been roughly constant from the present day far back into the pre-Cambrian.

Each major cycle of thrusting is of long endurance, and such "have occurred as a major revolution at least three times since the Cambrian." The fact of such cycles "seems clear in North America."

Termier,[30] director of the Geological Survey of France, says that the German theory has "undeniable charm and real beauty." It is

a beautiful dream, the dream of a great poet. One tries to embrace it, and finds that he has in his arms but a little vapor or smoke; it is at the same time both alluring and intangible.

With Termier and Diener, the writer agrees that Wegener's hypothesis stands upon the very unsound method of departing from the theory of the permanency of position of the earth's greater configurations of continents and oceans, and opposing to it one that unites all of the present lands into one enormous continent that endured until middle Mesozoic time, when it began to break up and the parts to drift into the positions seen to-day. We are on safe ground only so long as we follow the teachings of the law of uniformity in the operation of nature's laws. The battle over the theory of the permanency of the earth's greater features introduced by James D. Dana has been fought and won by Americans long ago. In Europe, however, this battle is not yet fought to a conclusion, since there are leading geologists who still follow Lyell and believe in the

---

[30] P. Termier, The Drifting of the Continents, Ann. Rept. Smithson. Inst. for 1924 (1925), pp. 219–236.

impermanence of the continents and oceans, and others who do not hesitate to push the earth's poles anywhere in order to explain single floral or faunal peculiarities.

Long before this, it has become evident to the reader that the writer is iconoclastic toward the Wegener hypothesis as a whole. On the other hand, he is wholly open minded toward the idea that the continents may have moved slowly, very slowly indeed, laterally, and differently at different times. Every student of tectonics, in his reading during the past 15 years in regard to the generalizations attained through a study of mountain structures and their meaning, must have said to himself again and again that there has been actual differential continental displacement. These generalizations, when based upon the individual and smaller mountain ranges, are not impressive, but when one begins to consider the Cordilleras of the United States, with their present width of more than 1,000 miles, the question looms large as to how much western California has moved to the east. No one has yet figured this out. Furthermore, when one turns to the Alps and is told by the best of authorities that their present width of some 150 miles was originally 500 and perhaps 625,[31] which means that their southern limit has moved from 350 to 475 miles to the north, he begins to remember the statement of Galileo in regard to the earth: "And yet it does move." Even more impressive are the statements of Termier regarding the mountains of central Asia, which have a combined present width of 1,845 miles from north to south, but which originally had an estimated width of 3,600 miles. In other words, the foreshortening may have been of the order of 1,800 miles. Accordingly, we are obliged to conclude that the continents do actually move extensively, but so slowly that it has taken Asia many hundred million years to accomplish the previously mentioned movement. But do these movements mean that the whole, or even parts, of the granitic sial have moved horizontally as extensively through the basaltic sima as postulated by Wegener? The writer is not the one to answer this question, but he feels that we must be open minded toward at least some unknown amount of continental displacements. Nevertheless, like Termier, he is "struck less by the mobility than by the permanence" of the earth's greater features.

IN RETROSPECT

Daly's new book, Our Mobile Earth, sounds the keynote for the attempt to save the germ of truth in the displacement theory and reconcile it with the facts that geology already has at hand. Following his lead, the writer has set down below the sequence of earth

[31] The compression of the Alps is estimated by Staub (Der Bau der Alpen, 1924, pp. 7–8) as amounting to between 690 and 1,035 miles, while Heim will only say that it is well over 185 miles.

development that he finds necessary to fit our determined geologic chronology, on the one hand, and the known development and distribution of ancient faunas, on the other. He realizes that this plan, as well as that of Wegener, presents at least one difficulty for which no solution is yet in sight—namely, the breaking down of the land bridges between continents and of the many borderlands, but he is confident that the geophysicists will in time find the way in which this was accomplished. In any event, it seems less insurmountable than the many inaccuracies and "imaginings" that stand against the theory of Pangaea.

Cosmic time, the writer believes, closed with a molten and layered earth that gave rise, not necessarily to a universal granitic crust (sialsphere), but either (1) to a localized and variably thick one, covering far wider areas than those of the present continents, or (2) to a universal one, very thin over what are now the Pacific and Antarctic oceans; what there was of a granitic shell over these destined oceanic areas was "swallowed and digested" by the basaltic substratum or simasphere during the Archeozoic. Over this cold crust of sial and sima may have lain a universal ocean but with probably not more than half the amount of water now on the face of the earth; the rest came during geological time. The granitic skin in the places of its occurrence was thinner than it is now, and the basaltic substratum, largely glassy, was therefore very mobile because of the greatly heated condition of the interior earth. Geological time had just begun with the dawning of the Archeozoic era, and about one thousand five hundred million years of geological history lie between us and this beginning of earth record in the rocks.

Archeozoic time was one of greatest crustal unrest, for everywhere the thin and localized sialsphere was being domed into short mountain ranges, locally folded, compressed, and thrust over one another, and through the deep wounds of fracture rose fluid granite and over the surface vast lava flows. The sialsphere, then an island world, was being crowded and welded together into greater and greater continental islands, between which lay seas, and with seas, rain, and air came into full play the phenomena of erosion and sedimentation. This topographically and geographically kaleidoscopic era may have endured during one-third of geological history.

Proterozoic time was another era of marked sial shifting that lasted through the greater part of another quarter of geologic history. But long before the close of this era the sialsphere appears to have been welded into three zones of transverse or latitudinal lands of great extent, namely, Holarctis, Antarctis, and Equatoris (fig. 4). The latter embraced South America, a land bridge across the present mid-Atlantic, Africa, Madagascar, and Lemuris, including India.

Antarctis had the Antarctic lands, with extensions to South America and to Australia, which was then a part of this great polar land. To the north of and as well in various places across Holarctis, the great northern continent, were shallow-water geosynclinal seas, while to the south of this greatest of land masses lay a vast middle ocean, Suess' Tethys, and its several extensions, all of which basins are now almost wholly squeezed into the mountains of Euro-Asia. Between Equatoris and Antarctis lay the large oceanic parts that are now united into the Antarctic Ocean, while the father of oceans, the Pacific, remained where it started and continued to evolve into ever greater proportions during the Archeozoic, attaining maturity about middle Proterozoic time.

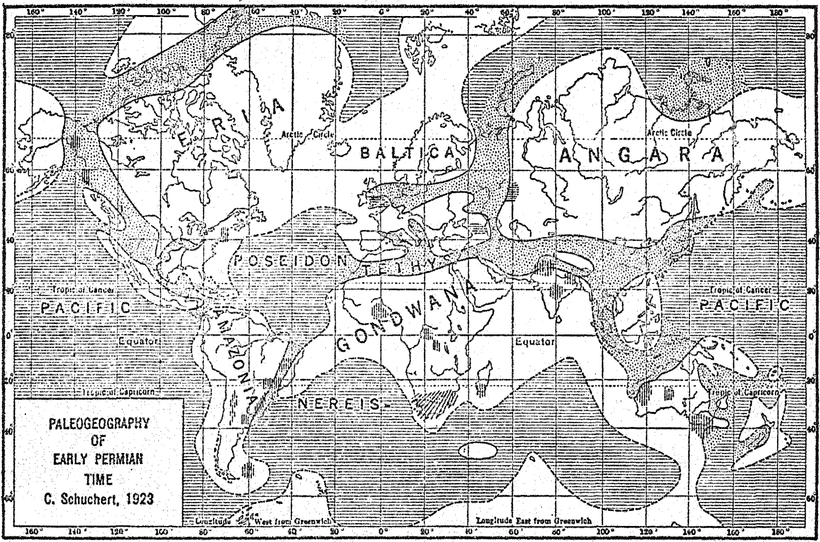


FIGURE 4.—Paleogeography of early Permian time. Oceans are ruled, epeiric seas and Tethys dotted, and places of glaciation lined (vertical lines, areas of proved glaciation; horizontal lines, those of uncertain glaciation). In the north is transverse Holarctis, in the center Equatoris, and in the south Antarctis. Note the borderlands of the Americas, which have since gone deep below sea level

Granted these or similar conditions, progressive geology meets the knowledge of orthodox geology and grants it the permanency of the earth's greater features, a knowledge on which the biogeographer of ancient life has built his paleogeography; he must have all this—the long and intricate migration routes—to explain the evolution that the migrating hordes have undergone. A Pangaea, the postulated single continent that began to rift in the Carboniferous and split and wandered apart after Jurassic time, will never explain the life of the seas and lands as seen by the paleontologist.

The Paleozoic saw no marked changes in the major features of the earth's face, but the many readjustments in the continental

masses toward the close of this era through their combined effect sounded the prophecy of doom for large parts of the sialsphere, since some land-bridges and most borderlands throughout the Mesozoic era were being absorbed by the periodically heated basaltic shell or simasphere. Cenozoic time completed what was begun during Carboniferous time.

The writer's long training in historical geology and his close study of Suess' Antlitz der Erde make it easy for him, after reading Daly's book, to throw the above new dress over the displacement theory, but he still realizes its many difficulties and hears the warning of Father Time that the rising generation will many times dress and redress the features of our Mother Earth before geologists and paleontologists will see her correctly in her evolving form.

ON CONTINENTAL FRAGMENTATION AND THE GEOLOGIC BEARING OF THE MOON'S SURFICIAL FEATURES [1]

By JOSEPH BARRELL [2]

[With three plates]

EDITORIAL PREFACE

Considerable delay in editing parts of Professor Barrell's unpublished work has been unavoidable; and as some of the articles, including the one presented herewith, are of a highly speculative nature, a portion of their original interest has been lost with recent progress in various fields of study. If the author were living to-day, without doubt he would make changes in this paper before giving it to the printer. Accordingly there has been some hesitation in offering the article to the public at this date. It is felt, however, that the central hypothesis, stated and developed with Barrell's characteristic breadth of vision, is still valuable in the field of philosophical geology. Moreover, in fairness to him, the full statement of his views on ocean basins should appear, as preliminary brief outlines of these views have not been universally understood and consequently have received invalid criticism.

During his last years Barrell's advanced teaching and some of his writings were colored with his thinking on problems of the relation between continents and ocean basins. His well-known studies in isostasy led naturally to an inquiry into the possible mechanism of continental fragmentation, a process for which he saw the evidence in geologic history as well as in certain tectonic features of the present. In 1918 he published an outline of his views in a short section of an article entitled "The Origin of the Earth,"[3] attributing the inception and enlargement of ocean basins chiefly to the rise of basaltic magmas from the subcrust. This short preliminary treatment, and also a later summary by Schuchert,[4] stated all essential points of the hypothesis, but without explanatory detail. The proposed mechanism has been criticized on the ground that vertical intrusion can only transfer matter from one part of the lithosphere to another, without altering the average density and so disturbing isostatic balance. The fallacy of this objection will be evident to the reader of this paper, as one of Barrell's fundamental postulates places the source of the great basic intrusions below the level of isostatic compensation. On this assumption the

[1] Reprinted, by permission, from American Journal of Science, Vol. XIII, No. 76, April, 1927.

[2] This article is part of an unpublished manuscript completed in the summer of 1917 and entitled "The Genesis of the Earth," a portion of which was published by Barrell under the title "The Origin of the Earth" as ch. 1 in The Evolution of the Earth and Its Inhabitants (Yale University Press, 1918). It has been editorially revised by Dr. C. R. Longwell.—CHARLES SCHUCHERT.

[3] Ch. I in The Evolution of the Earth and Its Inhabitants, especially pp. 39–43.

[4] Pirsson and Schuchert, Textbook of Geology, Pt. II, revised edition, p. 132, 1924.

density of the intruded lithosphere is necessarily increased, and the results outlined by Barrell are in full accord with the doctrine of isostasy.

It would be possible, by rewriting certain portions of the paper, to bring it more nearly into harmony with the most recent data and viewpoints. However, it is thought best to publish the article essentially as Barrell wrote it, with some comment on points that will be considered either wrong or questionable in the light of present knowledge. For example, the thickness of the acidic crust assumed by Barrell is too great according to recent findings in more than one field of investigation. After careful analysis of data from studies in radioactivity Jeffreys states, "Hence the theory enables us to make the quantitative suggestion that basic rocks predominate in the crust at a depth not greater than 16 kilometers." [5] Later, discussing seismological data, he also concludes "that the thickness of the granitic layer of the continents is of the

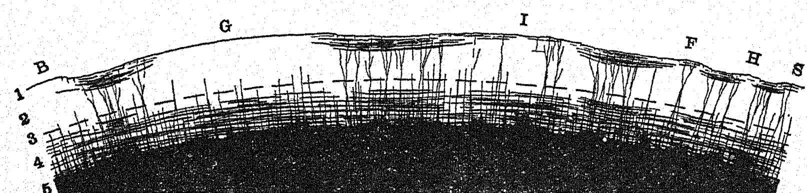


FIGURE 1.—Diagrammatic section across the North Atlantic, to illustrate theoretic relations of basic intrusions rising from the basaltic asthenosphere into the original, more acidic lithosphere, resulting in continental fragmentation in obedience to the forces reestablishing isostacy. Horizontal scale, ca. 480 miles = 1 inch; vertical scale considerably exaggerated

B, Baffin Land; G, Greenland; I, Iceland; F, Faroe Islands; H, the Hebrides; S, Scotland and Ireland.

There are also indicated—

1. The surface profile, exaggerated, ocean water omitted.
2. The granitic or dioritic lithosphere, strongest in its middle part, containing in its upper part lopolithic intrusions of basic rock.
3. The mean depth of isostatic compensation, the base of the lithosphere. It has in reality no sharp boundary.
4. The upper part of the asthenosphere, or shell of weakness, penetrated by basic magmas from below and yielding to warping loads in the crust above. The original rock is probably of an intermediate chemical composition, that is, a diorite.
5. The thick basic shell. The part here shown is solid, like the rest of the earth, but generates molten rock. This tends to rise to a higher level. Since it is a source of magmas, it is presumably also weak and forms the deeper part of the asthenosphere.

order of 15 kilometers." [6] Joly, from studies in radioactivity in which he considers only the effect of uranium and thorium, concludes that the continental crust is not over 31 kilometers thick, assuming that it is granitic throughout.[7] Holmes and Lawson,[8] estimating the additional effect of potassium, have reduced the figure to 15 kilometers, in close agreement with Jeffreys' result. These estimates are conspicuously smaller than the thickness of 50 to 75 miles assumed by Barrell, but the discordance is not necessarily as great as it may appear. Most of the results based on studies in radioactivity assume a shell made of typical granite throughout, with a uniform content of the radioactive

[5] Harold Jeffreys, The Earth, p. 87. Cambridge University Press, 1924.

[6] Idem, p. 179.

[7] J. Joly, Surface History of the Earth, pp. 71–73. Oxford University Press, 1925.

[8] Arthur Holmes and Robert W. Lawson, Potassium and the Heat of the Earth. Nature, May 1, 1926, pp. 620, 621.

substances.[9] Barrell, both in his discussion and in his diagram (fig. 1), postulates that granite near the surface grades downward into diorite, with a corresponding decrease in the radioactive materials. Even so, it is probable, from the best data available, that the upper limit of the zone with basaltic composition lies higher than is indicated in Figure 1. Possibly the lower limit of isostatic compensation lies wholly within this basic zone, and not in a dioritic zone as indicated by the figure. If this conception is adopted, the black of the figure should be extended upward into the lower part of the lithosphere, and conduits leading to the higher intrusive bodies should be pictured as transgressing a zone of solid basic material before entering the more acidic portion of the crust. Under such a conception the mechanism proposed by Barrell would encounter difficulties, as there can be no effective change of volume in the lithosphere so long as the material at its base has essentially the same density as the ascending magma.

If the features of Figure 1 are taken literally, the form of the intrusive bodies may be open to question. In his later years Barrell was impressed with the lopolithic form of certain large basic intrusions; and, judging from the figure, he considered this form as probably predominant. Clearly such a conception must assume a horizontal gneissoid or schistose structure in the granitic shell. However, this question is of only incidental interest so far as the present paper is concerned. In the text Barrell suggests that the intrusions in the upper part of the shell have the form of "lopoliths and batholiths." Figure 1 is to be considered merely as a diagrammatic representation of the mechanism assumed. The essential point is concerned with the volume of basic intrusions and not their form. As Barrell points out, the volume necessary for the task involved in the problem is formidable, and the mechanical difficulties of intrusion on the scale assumed are increased by the present-day conception of a thin granitic shell. It is a question whether he might not now want to assign a larger rôle to extrusion as a cause of crustal foundering. Arguments for such a conception might be based on the great thickness of Keweenawan lavas, mentioned in the paper, as well as on phenomena of the lunar maria.

The merits and weaknesses of Barrell's hypothesis, as seen from our present viewpoint, may be discussed at much greater length; but it is not the purpose of this preface to present a full critical analysis.

ON CONTINENTAL FRAGMENTATION

INTRODUCTORY

The outer crust of the earth, granitic in its upper part and somewhat more basic at depth, is held to have a thickness of from 50 to 75 miles. It is very strong and is marked by broad variations in density amounting to as much as 5 per cent, and by more local variations up to 10 per cent, these differences corresponding to the broader relief of the earth's surface. Below this lies a thick, hot, basic, rigid yet weak shell, the asthenosphere, or sphere of weakness. The problem of the origin of the ocean basins and the continental platforms consequently resolves itself into one of the origin of the

[9] Jeffreys made an estimate based on the assumption that the radioactive content falls off exponentially with depth.

density differences in the lithosphere and the maintenance of the heated and weak condition in the asthenosphere.

Uranium, in degenerating through radium to the stable element lead, develops an enormous amount of heat, but at so slow a rate that the whole duration of geologic time has not sufficed to eliminate it from the crust of the earth. Uranium and thorium, the parents of the radioactive series, are widely though sparsely diffused through the lithosphere. If they extend with their amount at the surface down to a depth of 40 miles,[10] they must supply heat to the surface as fast as it is lost by radiation into space.

The small content of radioactive elements in the basaltic shell or asthenosphere below the granitic crust of the continents would then supply that slow increment of heat which is necessary to generate new molten rocks. The granitic shell loses its excess heat by conduction to the atmosphere, but the asthenosphere is so deeply buried that its heat can not escape, but must slowly transform some of the solid rock into liquid form. Reservoirs of molten rock gather until their mass, combined with their decreased density in the fluid form. enables them to work their way into and through the lithosphere and demonstrate their existence in igneous activity at the surface of the earth. The magma which thus comes from the greatest depth and in greatest volume would, because of the initial density stratification, produce a notable increase in the density of the outer crust. In order to reestablish isostatic equilibrium, such a region must subside.

Most of the igneous rock of later geologic ages which has been intruded into the outer crust beneath the present continents clearly has not increased the density sufficiently to produce a foundering and would appear therefore either to have come from somewhat higher levels or to have risen in smaller quantity. In some regions, however, as in that of the Lake Superior Basin, large masses of basic magma do seem to have overweighted the crust in an early geologic period and produced a tendency to settle as a basin. The same effect may have taken place to even a larger degree in some regions of notable recent subsidence, as in the Mediterranean Basins. In the earliest times, following the solidification of the earth, the forms and relations of the ocean basins suggest that dense molten matter from the depths of the earth broke into or through the outer crust, on a gigantic scale, eruption following eruption until the widespread floods had weighted down broad areas and caused their subsidence into ocean basins.

As seen in the lava plains of the moon, such an action, once started at a certain point, is conceived to have gone forward with widening radius, leading to the origin of the many rudely circular outlines

---

[10] This figure is greatly reduced by recent estimates. See Editorial Preface, with footnotes.

characteristic of the ocean basins. The process left great angular segments of the original lighter crust as continental platforms standing in relief between the coalescent basins. The waters gathered into the basins and the continents emerged.

Most American geologists hold strictly to Dana's theory of the permanency of the continents and ocean basins, whereas European workers in general stand by the older view that ocean basins are broken-down portions of the granitic shell. We may also include this grander process of crustal change under the term of continental fragmentation. Great intercontinental troughs, such as the Red Sea and the Caspian, are thought to have been made in later geologic times by fracture of their margins and subsidence of their floors. The writer accepts the European view, since, in spite of its difficulties, it yet accounts for many geological relationships. If continental fragmentation is real, it has a strong bearing upon the general problem of the origin of ocean basins, for the progress of fragmentation is in reality a continuation of the formative process. Through fragmentation the margins of the continents break down into the oceanic depths and enlarge them, and at the same time diminish the areas of the land.

INDICATIONS OF CONTINENTAL FRAGMENTATION

The ocean basins, including slopes and deeps, occupy two-thirds of the surface of the earth. In form they are made up of coalescent, rudely circular or polygonal segments of the crust. The great Pacific Basin covers nearly one-half of the globe, is fairly regular in outline, and the structure of the mountain systems which face it is related to its margins. Along the western coasts of North and South America the parallelism is most conspicuous. Eastward from Asia and Australia, on the other hand, the mountain systems advance into the Pacific as chains of islands convex toward the ocean. On both sides of the Pacific the structure shows the mountains to be much younger in origin than the ocean basin. This is what Suess has named the Pacific type of continental margin. Fragmentation on a large scale, if it ever occurred there, must have been antecedent to the development of the present mountain systems.

The margins of the Atlantic and Indian Oceans show, however, a very different relation to the continental structure. Here the continents protrude into the ocean in sharp southward-pointing wedges, and they face the sea as table-lands of ancient rocks. The sedimentary systems are more numerous in the continental interiors than on these margins, and the ancient rock structures are in general cut across by the shorelines, showing that they are older than the present margins of the ocean basins. This type of coast Suess calls the

Atlantic type, and takes it as an indication of cross fracturing and foundering of portions of the continents in later geologic ages.

The rift valleys of equatorial Africa and the deep narrow basins in the western United States, such as Death Valley, are known to be sunken blocks founded by fractures. The Red Sea, the Gulf of California, and Davis Strait bear the marks on their borders of being similar but larger examples. These troughs therefore appear to be grabens, formed by recent sinking of blocks below sea level, and the adjacent lands of ancient rocks still stand high because they are not yet reduced by erosion.

From these faulted embayments of the sea it is but a step to certain islands which appear to be ancient remnants of land completely surrounded by the spreading ocean basins. Such upstanding pedestals are the "horsts" of Suess. Madagascar, off the east coast of Africa, is the most striking of these, consisting of a table-land of ancient crystalline rocks stepping up in successive levels and partially skirted by a fringe of Cretaceous and younger strata. Its structure suggests that it has been isolated from Africa and from India by fragmentation which began to be evident in Cretaceous time. In further support of this conclusion is its archaic mammalian fauna, preserved there as in an asylum, and protected by the barrier of the ocean from the predacious higher mammals of the adjacent continents.

The Ægean Sea appears to be a region breaking up and foundering in the present geologic period. The mountain structures are cut across and terminated by great faults that bound the sunken areas. It is a region of present geologic movements and consequent violent earthquakes. Deep, unfilled pockets exist in the adjacent seas. Finally, on the island of Kos there are river deposits which were laid down when it was surrounded by higher land.

Passing to more ancient times, the Paleozoic marine sediments of Great Britain seem to have derived their materials chiefly from a land situated to the northwest, which Hull called Atlantis. On the other side of the Atlantic, the thick formations of the Appalachian system came from the vanished Paleozoic land to the east which has been named Acadia, and which formed the northern part of the greater land of Appalachia. The writer has calculated elsewhere [11] the volume of sediment deposited in Upper Devonian time and finds it so great that the land supplying it would seem to have necessarily extended out into what is now the ocean basin.

Let us turn next to the nature of the biologic evidence. Paleontologists have pursued their studies of the ancient marine deposits so far that they are now able to tell whether the entombed fauna in any

[11] J. Barrell, The Upper Devonian Delta of the Appalachian Geosyncline. Amer. Journ. Sci., 37, 225–253. 1914.

period has come from the Pacific, Arctic, or northern Atlantic realm. At long intervals the geosynclinal seas widen, so that their faunas commingle in the great interior waters and become cosmopolitan. At other times these seas do not coalesce and the faunas remain provincial. Therefore during the Paleozoic many of the American faunas derived from northwestern Europe are distinct from those of southern Europe, certain faunas from the Maritime Provinces of Canada are easily distinguishable from their contemporaries in the interior Appalachian region. Nevertheless there were times, as in the Middle Cambrian, when the eastern Canadian faunas were closely identical with those of northwestern Europe, although both were quite distinct from the faunas of southern Europe and the interior of the United States. Contemporary faunas from the latter area correlate best with those of China, both regions belonging to the Pacific realm. Such peculiar relations during times distinguished by an absence of marked climatic zones have led paleontologists to hold that in the Paleozoic a land mass extended unbroken across the North Atlantic Ocean, enabling the shallow-water faunas to migrate along the northern and southern shelf seas. This inferred northern continent included parts of Canada, Greenland, Iceland, Scandinavia, and Britain in one land which has been named Eria.

Turning to the evidence supplied by the land life, it is to be noted that in the Pennsylvanian period the plants of the great coal swamps were largely identical in eastern America and western Europe. The most striking relationships are shown by the flora of the Southern Hemisphere in the early part of the Permian period. At that time the Southern Hemisphere was subject to recurrent glaciation on the vastest scale known in earth history. Continental ice sheets existed in tropic India, southern Africa, and South America, Australia, and Antarctica. A special stress flora arose in the Southern Hemisphere adapted to these severe climatic conditions, and the whole assemblage is known as the Glossopteris or Gangamopteris flora. This flora has been recovered from all these and other southern lands and is held to have originated here, as it is not represented at this time in the Northern Hemisphere. The spores of these plants could not have crossed thousands of miles of ocean water, and it is equally incredible that a nearly identical assemblage of species could have arisen independently in separated continents. These and similar facts have led many geologists of Europe and America to a belief in the great Paleozoic continent of Gondwana, stretching east and west through the Southern Hemisphere and uniting South America, Africa, India, and Australia. In the west, Gondwana was separated from Eria by the ancient Mediterranean, which Suess named Tethys, and by the North Atlantic Basin, which Schuchert calls Poseidon.

The theory of the ancient land bridges, created by geologists and more especially by zoologists and botanists, has, however, been carried too far. It is often easy to explain any real or fancied organic interrelationships by such a hypothesis, but sound science demands that there should be a careful examination to see if the facts to be explained can not be harmonized without recourse to bridging and rebridging deep oceans. Matthew,[12] for example, has shown that the mammalian faunas of the Cenozoic era do not necessarily imply the existence of Gondwana at this time, and Chamberlin has argued against the existence of this land bridge at any time.

Nevertheless most European and some American geologists hold that a large number of organic relationships exist which establish the former existence of the above-mentioned east and west continents, and that the configuration of the present continents has come about since Cretaceous time.

ARGUMENTS AGAINST CONTINENTAL FRAGMENTATION

The arguments against the acceptance of continental fragmentation, as the writer comprehends them, may be summarized as follows:

First. There is no direct evidence of the existence of former lands in the present ocean basins. Moreover, some of the supposed paleontologic evidence calling for land bridges may perhaps be explained as well by existing routes, and organic evolution under similar climatic conditions may have brought about likenesses in form where no close relationships actually exist.

Second. If the Paleozoic continents stretched east and west across the Atlantic Ocean, there should still be recognizable east-west trends in the relief of the ocean floor or in the bounding lands; the former land bridges, even if submerged, should still be distinguishable. It is, of course, true that submerged plateaus do connect Australia with Asia and Antarctica, and in the North Atlantic there is the evidence of the Wyville-Thomson Ridge connecting Scotland and Iceland. On the other hand, the mid-Atlantic plateau runs north and south, and the ocean is as deep over the site of Gondwana as it is elsewhere.

Third. The continental platforms as a whole are known to be in rather close adjustment to the density of the outer 50 to 100 miles of the crust. To suppose then that an ancient continent has partially foundered requires that the crust must here have become on the average from 3 to 5 per cent denser. There is as yet no known geologic process which could bring about such an increase in density. Unless such a process is shown to be possible, the other evidence must

---

[12] W. D. Matthew, Climate and Evolution. Ann. N. Y. Acad. Sci., 24, 171–318. 1915.

become of compelling force and definiteness before the hypothesis of fragmentation can be accepted.

These counter arguments will now be taken up for discussion. The positive evidence bearing on the first one has been given under the previous topic, and is of such weight that most European and some American geologists have accepted fragmentation as a fundamental phenomenon in geologic history. The objections stated under the last two heads, however, have never been squarely met. In fact, they have gained most of their strength in America in recent years through the recognition of isostasy as a real and measurable factor. It is these objections that will now be more fully dealt with.

As to the relief of the ocean floors, we really know very little about it in detail. The usual method of exploration, such as that pursued by the *Challenger* expedition, is to make soundings at distances of many miles, along lines that are hundreds of miles apart. In fact, the map of the Atlantic between Brazil and Africa published by the Institut für Meereskunde, Berlin, gives but about 150 soundings. If the elevations on the land were similarly determined and at such distances apart, a wholly erroneous mental picture of the gentleness of land relief would be obtained. On the other hand, the margins of the ocean basins must become smoothed out by the deposit of land waste, but such smoothing would extend generally not more than 200 miles, and therefore could not obscure the larger relief of the basins. Moreover, detailed surveys for cables have revealed surprising irregularities in places, and regions are known that have to be avoided.

This sharp relief seems to be most largely due to submarine faulting and submarine volcanic activity, but it is also possible that some of it is due to the preservation of an ancient land surface, or to old faults connected with subsidence. If the north-south trends on the floor of the Atlantic actually exist, they may be related to the volcanic activity of Cenozoic time, but it is more probable that they are due in part to horizontal pressures like those generating mountain folds. However, in the submerged mountain ranges on the floor of the Pacific this relation of ridges to volcanoes is quite clear. From these considerations we see that the present relief of the Atlantic bottom may be chiefly due to causes that have operated since the breaking down of Gondwana in the later Mesozoic, and accordingly would tend to obscure the original east-west trend of the lands.

If the fragmentation of Gondwana is due to the same causes responsible for the original ocean basins, it might be expected that subsidence under these same causes would take place to about the same amount. Accordingly, the successive additions to the ocean floor need not be marked by a simple steplike character. Then, too,

the different oceans and the different parts of the same ocean show similar ranges in depth.

Future detailed investigations of selected parts of the ocean floors may bring strong evidence to bear for or against the hypothesis of fragmentation, but our present knowledge on this subject is indefinite. The arguments here set forth merely show that fragmentation of parts of continents is not disproved by what is now known as to the relief of the ocean floor.

Let us turn, then, to the third argument, that dealing with change of density and resulting isostatic movements as the immediate cause of fragmentation. On the continents such changes in density clearly seem to have taken place, but the evidence is best where the change is toward a lesser density and where parts of continents are lifted up into plateaus. As an illustration, most of the great Cordilleran area of North America during the Mesozoic tended to lie not far from sea level. Here ranges of mountains were uplifted from time to time, but their waste was deposited in adjacent regions as sea deposits, or laid down as continental formations at a low elevation. The region of the lofty Colorado plateaus shows, in fact, a stratigraphic section which includes deposits, most of them marine, ranging from the early Paleozoic to the close of the Mesozoic. During all of that vast time, occasional regional subsidence with resulting sedimentation was the rule. No uplift occurred great enough to permit erosion to destroy completely the older strata. But during the later Tertiary a reverse movement set in; broad uplift of fault blocks took place so that these masses now constitute plateaus from 6,000 to 11,000 feet in elevation. The region is shown by geodetic observations to be in the usual degree of isostatic equilibrium. There would appear to be evidence here, therefore, of a regional decrease in density in late geologic times. The cause of such a decrease would appear to be the rise of molten magmas and the expansion of the cover rocks due to the accession of heat. Vast volumes of magma are needed to account for a change of density in the whole crust sufficient to cause an isostatic uplift of from 1 to 2 miles, and these volumes must therefore be at such a depth that large local surface outpourings would not be possible as proof of their presence. The Cordilleran belt as a whole, on the other hand, many hundreds of miles wide and running the length of the continent, was the scene of regional igneous activity during the Tertiary era on as large a scale as is known anywhere since the Proterozoic. Not all parts of the surface have been covered with extrusive rocks, but the intrusions in depth must be far wider, and for the Cordilleran province as a whole the relationship of igneous activity to the great Tertiary uplift seems clear.

RELATIONS OF ISOSTASY, BASIC INTRUSIONS, AND CRUSTAL FOUNDERING

Let us turn now to the opposite side of the problem, that is, to the possible relation of igneous intrusions of high density to regional subsidence.

Granites, the siliceous or acidic end of the igneous series, have, on the average, 70 per cent silica and a specific gravity of 2.70. Gabbros, the dark, coarse-grained, basic intrusives of the same chemical nature as basalt, average 50 per cent of silica and a specific gravity of 3. The extremely basic rocks, pyroxenites and peridotites, have an average silica content of 45 per cent and a specific gravity of about 3.30. The density of these rock types is therefore seen to range through 20 per cent.

At Sudbury, Ontario, a great intrusion of gabbro shows after ages of erosion as a great lens 36 miles long and 17 miles broad. The thickness ranges from half a mile to 2 miles, and in form it is a saucer-shaped body concave upward.[13] It is the shape of the mass that is so interesting here, since it appears that the floor subsided under it during or after the intrusion. Such a saucer-formed body differs from a laccolith, in which the intrusion domes up the cover. This fundamental distinction in form appears to be related to the high density. Being denser than the surrounding rocks, the igneous mass has settled down.

The Duluth gabbro which underlies the southwest part of Lake Superior is on a far larger scale than the Sudbury intrusion and accounts for the synclinal structure of this part of the Lake Superior Basin. In the Middle Keweenawan, basaltic lavas were poured out on the surface of the earth over the western half of the basin to a maximum of more than 20,000 feet in thickness, the bottom subsiding as the successive floods welled forth. Thus the original basin structure of Lake Superior was established at this remote time, but the present depression occupied by the lake waters seems to be of recent geologic origin, as though, at a time of relatively recent crustal disturbance, the great weight suspended here in the crust had, after an age-long rest, dragged it down another stage. The glacial ice occupied this ready-made trough and by its weight may have deepened it a little further. Although the extrusives are so thick, the intrusives as shown in the Duluth lopolith are known to be much thicker. They presumably overlie still deeper and larger reservoirs of igneous rock, offering a yielding base to the lavas above, as otherwise depression of their floor would hardly have gone forward so readily during the period of igneous activity.

---

[13] =lopolith of Grout. Amer. Journ. Sci., 46, 516–522. 1918.

24034—29——20

Turning now to a more recent and still wider exhibition of basic extrusions, during the early Oligocene basaltic lavas and ashes were poured out on Scotland and Ireland, the Faroe Islands, Iceland, and the eastern and western coast of Greenland. In the detrital beds accumulated between the lava flows, fossil leaves of forest trees are preserved, testifying to a warm temperate climate at that time in Greenland; they also indicate a close relationship between the lands, suggesting connection at that time. Geikie estimates the thickness of the basaltic series in Iceland at 10,000 feet, and in northwestern Greenland at 4,000 feet. The flows are scattered over a distance of 1,800 miles and their superposed sheets underlie separate plateaus whose edges face the ocean in steep scarps. It would appear, therefore, as if the oceanward continuations of these lava plateaus had foundered. Between these widely separated regions it seems probable that still larger areas of basalt must occur, which are now at the sea bottom.

These basalt-covered lands are portions of the ancient continent Eria, which connected northeastern Canada and northwestern Europe. Let us note first what the paleontologists have to say as to the date of its foundering, drawing their evidence from the fossil mammals found on the two sides of the ocean, and without considering the basaltic magmas as a cause for the separation of the lands. Schuchert states:[14]

> Greenland and the region eastward across Norway, Sweden, and Finland (Fennoscandia) were subject to great block faultings or warpings previous to the Pliocene, developing not only great rifts or graben but broad sinking areas as well, with a general trend to the northwest and southeast. This was the time when Eria was broken through, separating Laurentia from Baltica. Previous to the Middle Miocene this land was the bridge that enabled the mammals of Europe and North America to intermigrate. Periodically, but more especially during the Oligocene and Miocene [late Eocene and Oligocene], lava flowed widely through fissures over all these lands, the Faroe Islands, Scotland, and northern Ireland (Giant's Causeway). This foundering of the crust where the Norwegian sea now is, permitted the triumphant spread of the Atlantic into the Arctic Ocean.

The sea bottom between Greenland, Scotland, and Scandinavia is less than 6,000 feet deep, and therefore only about one-half the mean depth of the ocean. Assume a mean subsidence of 6,000 feet due to the intrusion of rocks which after solidification were 10 per cent heavier than the rocks which they displaced. This would require the intrusion of a mean thickness of 60,000 feet. The extrusions would be but a fraction of this, as judged by other regions where abyssal rocks are exposed, the extrusions serving only as an index of the greater masses below. The intrusions would presumably cover as

[14] Charles Schuchert, Pt. II of the Piersson-Schuchert Textbook of Geology, pp. 923, 924. 1915.

much as 1,000,000 square miles and attain a volume of 12,000,000 cubic miles. Even though these quantities are vast, they are not at all unreasonable in proportion to the areas concerned. There is reason to believe that the thicknesses beneath the Lake Superior Basin are as great, though not the area of the intrusions, and the volume of extrusions within that limited region has been estimated at 24,000 cubic miles. Even so, this amount is probably only a fraction of the volume of the associated intrusions. The ratio of the volume of the Lake Superior basic rocks of Keweenawan time, to those of the North Atlantic in the Tertiary era is therefore no more than in proportion to the areas involved.

To produce subsidence in central Asia through basic intrusion, several conditions would have to be met, as shown in Figure 1. First, the material would have to come from below the level of isostatic compensation in order to make the crust above that level heavier, as a whole, than it was before. The crust, or lithosphere, within which isostatic compensation exists is a shell of strength. In order, therefore, that isostatic adjustment shall take place, it must be underlain by a thick shell of weakness, the asthenosphere. This sphere is conceived of as highly rigid under vibratory stresses, but yielding readily under prolonged ones, probably by a process of recrystallization as in glacial flow. It is presumably then very close to the temperature of fusion, as this is the physical condition which permits in this shell the coexistence of high rigidity and low permanent strength. Basic magmas originating in its deeper part could, therefore, by aid of the smelting, drilling, and disruptive pressures of their included gases and the notably decreased density attending the fluid state, force their way upward into a colder and stronger shell of lower specific gravity than the solid phase of the intrusive.

The decreased density of the fluid condition over the solid phase of the identical magma is about the same as the difference in density between solid granite and solid gabbro. As long, therefore, as the intrusive was in a fluid state, there would be little or no tendency for net subsidence of the crust, a condition which probably still exists beneath Iceland, as shown by its geysers and active volcanoes. The crystallization of the magma and the dissipation of the excess heat of the thick intrusive masses would require a time comparable to the length of a geologic period. During this time it would slowly become denser; but, in proportion as this downward drag made itself felt, the crust, which was temporarily weakened by the intrusions, would heal and grow stronger. The subsidence, on the other hand, would require a slow lateral displacement of material in the asthenosphere. In consequence, the breaking down would be shown on the surface by great fractures and downfaultings.

As the sinking strain slowly increases in the outer shell, the immediate cause of its release—the trigger that sets the mechanism in motion—may be a compression of the earth's crust such as is manifested elsewhere in a mountain-making movement. To illustrate this effect of compression, take two laths and support them in horizontal position at the ends. Load one of the laths in the middle with a few pounds of weight. The load will produce only a slight elastic flexure. Now compress both with a horizontal thrust. The loaded lath will bend down and break under a slight compression which will hardly affect the other. Thus a movement of crustal compression acting horizontally through the whole lithosphere will tend to vertical warping of all tracts not in isostatic equilibrium, either upward or downward, according to the direction of the preexisting vertical stress. The surface expression of such warping is likely to be manifested as great fractures between blocks of crust. These faults pass miles below into broad flexures.

During the Middle and Upper Miocene occurred the final foundering of Eria, and also one of the greatest mountain-making movements since the pre-Cambrian. A sufficient geological interval had elapsed after the early Oligocene igneous activity of Eria for the solidification and attendant increase in density of the basic magmas, with consequent development of downward stresses. It is believed that in this way Eria was broken up and large parts of it foundered into the Atlantic Ocean.

The hypothesis of the relationship of continental fragmentation to basic intrusions on a large scale, reconciles the apparent conflict with isostasy and brings together harmoniously in the explanation of the foundering of Eria a number of otherwise apparently unrelated phenomena. Measured by this test the hypothesis is successful.

The example is, however, geologically recent and much of the evidence is preserved. The land bridge has broken down, but its pierlike remnants still stand as horsts in the ocean. In certain other cases the evidence is more or less indeterminate, as indeed is to be expected.

In northwestern India, the Deccan traps outcrop on the coast from latitude 17° N. to the Tropic of Cancer (about 22°), and extend inland halfway across the peninsula, occupying to-day 200,000 square miles and forming one of the greatest basalt fields of the continents. [According to Wadia,[15] however, the outliers in greater India indicate that the original flows covered an area of 500,000 square miles.] They are broken off by the shore line, the nearly horizontal beds rising in terraces or steps to elevations of

[15] D. N. Wadia, Geology in India, pp. 192–201. 1919.

several thousand feet and forming the Western Ghats. The flows and ash beds reach a maximum thickness of as much as 10,000 feet along the coast of Bombay. It would appear as if they once extended far seaward (perhaps across to Arabia), but that this western portion had broken off and sunk into the Arabian Sea. The date of the basaltic outpourings is fixed as latest Mesozoic, transitional to the Eocene.

Far to the south, in the early Eocene, Madagascar is thought to have been still connected with India, forming the hypothetic land of Lemuria, the eastern portion of Gondwana. The evidence here lies in the nature of the Madagascan fauna, which contains a primitive assemblage of mammals and is devoid of that more powerful and advanced placental fauna whose evolution dates from the later Eocene. The foundering of Lemuria and the spread of the Indian Ocean westward and northward may therefore be connected with the basic igneous intrusions of the previous geologic period, of which the Deccan traps are remnants.

On the other hand, the great Columbia Plateau of basaltic rocks in Idaho, Washington, and Oregon, which rivals the Deccan traps in magnitude, is not known to be connected with any adjacent subsiding area. The presence of basaltic flows does not in itself prove that there has been a rise of new basic magmas in great volume into the outer crust. All great cycles of igneous activity begin normally with the outflow of basaltic or the slightly more siliceous andesitic lavas. Throughout the Cordilleran belt the great intrusive masses which followed the extrusives are in part exposed by later erosion and are seen to be nearly as siliceous as the true granites. They are therefore called granodiorites. Their specific gravity is close to that of granite and very different from that of the gabbros. Hence the Columbia Plateau basalts are seemingly related to the granodiorite magmas and are probably underlain deeper in the crust by them.

The causes of continental fragmentation which have so far been suggested involve several postulates which should now be brought clearly into view.

First. There is involved the conception of an initial granitic crust grading down through an intermediate or dioritic one into a denser basaltic shell. This is of course not open to direct proof, but is an inference reached by a number of petrologists who have dealt with the profounder aspects of their subject.[16] This hypothesis of the layered nature of the earth is also in accordance with a number of lines of inference developed in the present work.

[16] See especially the comprehensive work by R. A. Daly, Igneous Rocks and Their Origin, Ch. VIII, 1914.

Second. The asthenosphere is taken as occupying a deep zone, possibly several hundred miles in depth, the upper part of which has the composition of a diorite, and is decidedly more acidic than the lower part, which probably has the composition of a gabbro or basalt. The dioritic zone has appreciably lower density than the basaltic one, quite apart from the effects of pressure. Most of the igneous activity within the continents is thought to originate in the dioritic zone, and this was notably true of the extensive fusion which gave rise to the Archean granites. A dioritic magma has between 55 and 65 per cent of silica, and is therefore intermediate in composition between a granite (65 to 75 per cent silica) and a gabbro (45 to 55 per cent silica). This intermediate magma, when it appears at the surface in molten form, gives rise to dark lavas known as andesites, many of which approach basalts in appearance. During the existence of the molten reservoir in the outer crust a separation of the fluid rock tends to take place, possibly by an early crystallization of the basic minerals, splitting the magma into basalts on the one hand and granodiorites or granites on the other. The latter accumulate especially in large bodies in the crust, and these are exposed in after ages by erosion and are revealed as the cores of mountain ranges. The processes of differentiation will therefore produce all kinds of rocks from whatever depth in the crust they come, but the relative volumes of the different kinds will be notably different according to the original composition. Such a difference in proportions is thought to distinguish the lavas of continents from those of oceanic islands, the latter being more dominantly basaltic. The difference pointed out is probably to be ascribed to the original depth from which the magma rises. It is true, however, that extrusions and intrusions of dominantly basic nature are known within the continents. When these rise to great volume they are thought to have risen from a deeper source; when occurring over broad areas they set up strains which work toward continental fragmentation in obedience to the laws governing isostasy.

Third. The periodic cause of the generation of magmas is believed to be radioactivity. The radioactive elements are known to be present in appreciable quantities in granites and basalts, so that if these rocks exist below a depth of about 40 miles,[17] heat is generated by them faster than it can be conducted away, unless some unknown inhibiting action is there present. If so generated, the heat must slowly increase and express itself in the liquefaction of rock. As the liquid rock increases in quantity it becomes able to work its way to higher levels. Most of it will slowly cool there, but some will melt its way to the surface. This convection effect will tend to

---

[17] This figure is greatly reduced by recent estimates. See Editorial Preface, with footnotes.

mix the originally separated intermediate and basic shells. The ultrabasic rocks, such as the metallic meteorites, have not been found to contain the radioactive elements, and therefore deeper shells of such composition, if they exist, have not been considered as entering notably into the mechanism of igneous activity. It is possible that the dense, rigid, and strong centrosphere consists of such ultrabasic materials.

Fourth. The rising magmas break through the strong outer crust only occasionally and in certain areas, notably along the zones of mountain building. F. D. Adams has shown that the great pressures existing within the crust increase the strength of rocks many fold, and this strength is not decreased by temperatures up to 550° C. The fact remains, however, that magmas do rise and the crust does yield in order to permit mountain making and maintain isostasy. This would appear to necessitate the hypothesis that the temperature is high enough to reverse the effects of pressure upon strength and that rock flowage takes place by recrystallization at temperatures approaching those of fusion. At considerable depths these temperatures of fusion are far above the limit of 550° used in the experiments by Adams. The zone of greatest strength would tend to hold the magmas down until they accumulate in sufficient volume to dissolve, drill, and break their way through this resistant zone. Above this they would tend to spread out in lopoliths and batholiths, and a portion would rise higher, forming, as volcanoes, safety valves for the internal forces. These relations are all expressed in Figure 1. The localization of fragmentation to certain regions may consequently be due, in large part, to the general resistance of the lithosphere, only rarely broken through in great volume. The basic magmas, because of their lower temperature of fusion, lower content of gases, and higher density, would have smaller power of penetration than more acidic magmas.

Fifth. Downsinking in obedience to the demands of isostasy is facilitated by the general heating of the whole crust below the zone of lopolithic intrusions. The heat of these intrusions must escape upward. Accordingly the rocks solidify and the outer crust becomes stronger; but below, the heat is held in, the upper limit of the asthenosphere necessarily has risen because of this higher temperature, and the crust as a whole has grown weaker to resist the vertical loads that are imposed by the new differences in density.

To sum up the argument, some periods, such as the Keweenawan, and certain regions, such as that of Lake Superior, are seen to be characterized by especially voluminous extrusions and intrusions of basic magmas. If the earth is layered in density, such heavy magmas would presumably originate deeper than those which are more siliceous. The siliceous magmas also give off basic fractions by differ-

entiation, but the exposed intrusives on the continents are mostly granite, and the basic portions represent a smaller volume. Great intrusions of basic magmas rising from the deeper asthenosphere would, under the principles of isostasy, produce subsidence. Regions in which the evidence is strongest for fragmentation show, in a number of cases, great outpourings of basic lavas reaching maximum thicknesses on adjacent coasts. The evidence for fragmentation is therefore paleontologic, physiographic, and structural. The strongest evidence, however, is paleontologic. If this evidence is strong, it can not be denied by an appeal to isostasy, as a mechanism of igneous activity, described in this topic, may be invoked which only requires a larger scale of action than that observed to have occurred on the surviving lands.

PERIODIC AND SECULAR SINKING OF THE OCEAN LEVEL

With the development of a solid crust came the origin of the oceans, and with every rise of magmas the volume of water has been increased. Therefore, throughout the geologic ages there has been a contest between land and sea, between the volume of ocean water and the capacity of the oceanic basins. From epoch to epoch the sea level is oscillatory, and from era to era there are progressive secular changes.

The widely flooded condition of most of the continents during the Paleozoic is shown by the accumulation of marine sedimentary rocks upon their surfaces. This result of a high ocean level is in contrast to the deep and widespread erosion of the highly emergent continents just previous to the Paleozoic era, and is most probably to be ascribed to the increase of water during the Paleozoic. On the other hand, it also appears that during the time of revolutions closing the eras, the ocean level sinks and the horstlike continents become highly emergent. Higher and higher the continents have risen during the later Tertiary until the mean elevation of the land has become about 2,400 feet, probably 1,000 to 1,600 feet higher than the mean elevation during the Paleozoic era.

Many geologists have assumed that the synchronous emergence of the several continents is due to a deepening rather than widening of the ocean basins. This, however, brings in difficulties with the theory of isostasy. The simpler view appears to be that during the times of revolution the ocean basins widen by continental fragmentation rather than deepen as a whole. At the same time, individual lands tend to warp up to offset isostatically the loss of rock previously removed by erosion.

The great revolutions are accompanied and followed by complete or nearly complete withdrawals of the sea. The continents are then

subject to excessive erosion, and thus arise the long-enduring breaks in the marine sedimentary records. These are also the times of most marked mountain making and of greatest progress in continental fragmentation. Then follow periods of higher ocean levels in which parts of the continents are again covered by the sea. Here then we see the cycle of the eras illustrated by the most marked changes of sea level, which distinguish Paleozoic, Mesozoic, and Cenozoic. What has been the still longer trend of geologic events?

The revolutions of the Archeozoic, accompanied by batholithic invasions of the continents on a world-wide scale, were followed by erosion of the continents down to the levels of crystalline rocks. Hence the ocean level was then low relative to the continents. During the Animikian (Proterozoic), however, the seas appear to have spread widely over the deeply eroded continents, but in the closing Proterozoic revolution there was a marked rising of basic magmas and a falling sea level, as no late Proterozoic marine records are known. This time of no or very scanty marine record Walcott has named the Lipalian interval. During the Paleozoic, on the other hand, a high sea level was the rule, and the Permian revolution, although it caused a general withdrawal of the seas, did not greatly change their mean level, as is shown by the lack of deep erosion of the previously deposited Paleozoic sediments. It is true that, on the whole, wider lands followed in the first half of the Mesozoic, but during the Cretaceous the oceans again invaded the continents in one of their widest floods. The Cenozoic, however, has witnessed an oscillating rise of the lands until now they appear to have a greater mean elevation than at any time since the Lipalian interval.

Smoothing out the crustal oscillations connected with periods and eras, it appears that a great cycle of progress has run through earth history. High and wide lands marked the Archeozoic and Proterozoic revolutions; fragmentation was apparently widening the earliest ocean basins and lowering the ocean levels, but the juvenile waters from the accompanying igneous intrusions reelevated them. Then came a long time, from the early Paleozoic to the close of the Devonian, during which the oceans rose and repeatedly spread over the lands. Since the later Paleozoic, however, the ocean level had tended to sink, and fragmentation appears to have gained on the accessions of juvenile water. The resulting wider, higher, and more diversified continental areas have favored the evolution of land vertebrates. Fortunate indeed has been the summation of these processes, for without this change in the general trend of the ocean level it is doubtful if the evolution of man could ever have been attained.

But the lands have been kept high above the increasing waters only by the breaking down of portions of their areas into ocean basins, a sacrifice which can not go forward forever if there is to be

continued an evolution of highest life. Is the earth striving to attain a final uniformity or radius, and, provided the solar energy is of sufficient duration, will a planetary history which began in a reign of fire end in the establishment of a universal ocean? Science as yet can not predict, for the end is hidden behind a deeper veil than that which conceals the beginning.

THE GEOLOGIC BEARING OF THE MOON'S SURFICIAL FEATURES

In studying the earth as a planet, we labor under the difficulty of observing only one example of a class. If the earth can be compared to a similar body, tests may be found that make more probable the hypothesis framed to explain the features and history of our globe. Fortunately the moon is such a body, and one so near that under high powers of the telescope features 500 feet in diameter may be distinguished. Geologists, their eyes turned toward earth, have sought but little knowledge in the heavens, though Gilbert, Suess, Shaler, and others have studied the moon with the vision of the earth scientist. Nevertheless, the features of our satellite reflect something of the history of the earth, and in particular support the hypotheses of the internal origin of the hydrosphere and atmosphere, as well as give evidence pointing toward the periodic growth of ocean basins by continental fragmentation. As throwing light upon such geologic problems of genesis, these features of the moon are consequently worthy of some detailed discussion.

The moon, at a mean distance of 238,840 miles, is by far the nearest celestial body. Its diameter, 2,163 miles, is but 27 per cent of that of the earth, and yet this is by far the largest ratio of any satellite to its primary in the solar system. In fact, the size of the moon really removes it from the class of satellites into the unique position of a small sister planet. The mean specific gravity of the earth is 5.53; that of the moon is 3.34. Consequently the mass of the moon is but 0.012 that of the earth, and gravity at its surface is but one-sixth of the same force at the surface of the earth. The earth's sphere of gravitative control extends outward to somewhat over 600,000 miles, far beyond the orbit of the moon. The gravity of the moon, on the other hand, is not sufficient to hold an atmosphere to itself. Such gases as emanate from its interior diffuse into space, and being within the earth's sphere of control have been in greater part added to the air and ocean of the earth. The moon has therefore never had seas, nor has it been subject to the gradational effects of air and water. It preserves in the rich detail of its surface features a record of its internal activities, a record similar to yet different from that which has been obscured on the earth by concealment beneath the sedimentary and oceanic envelopes or by destruction through the gradational forces of the atmosphere.

If, in imagination, the oceans should be removed from the earth and the planet were to be viewed from outer space, one of its most striking features would be the systems of mountain folds. These bear the evidence of being made by great compressive movements in the crust, and imply a condensation of the earth's body operating periodically throughout geologic time. This crustal wrinkling is clearly not due to external cooling, as Dutton, Fisher, and Chamberlin have shown. Chamberlin has given cogent reasons for holding that it is indirectly due to a condensation of the nucleus of the earth, and that the direct cause may be found in the enormous pressure acting thereon, due to the weight of the lithosphere. This pressure attains 45,000,000 pounds per square inch at the earth's center, a depth of 3,959 miles. The moon's center at a depth of 1,081 miles is subjected to only a small fraction of this pressure, equivalent to that which would be found in the earth somewhat less than 100 miles beneath its surface. This lack of high internal pressures seems, therefore, to explain the absence of important linear mountain systems on the moon.

The moon's face, as seen especially in the full moon (pl. 1), consists in part of a brilliant but rough surface interspersed with coalescent, smoother, darker areas which individually have irregularly rounded boundaries. To the naked eye these darker areas combine into the rude semblance of the features of a human face. As Galileo looked at these features through the first telescope, the resemblance of the darker areas to seas so impressed him that he named them "maria," giving to each unit a distinctive name such as "Mare Imbrium" (shown in pl. 3) and "Mare Serenitatis." Closer observation shows that these "seas" are in reality more or less smooth dark lava plains, dotted with occasional volcanic craters. Over the brighter portions, beyond the lava plains, the craters stand very thickly, older craters are more or less obliterated by numerous younger ones superimposed upon them, and the whole constitutes a chaos (shown well in pl. 2). Zöllner has computed from the amount of light received at different angles from this surface that the average angle of slope is at 52° to the horizontal. This corresponds to the reflection from a rough, loose surface of cracked stone or a surface of steep, rough, and vesicular lava. The comparative smoothness and darker color of the maria indicate a comparative absence of these features, resulting in a different light refraction.

Loewy and Puiseux find that three successive surficial levels may be distinguished in the moon. The first is the rough, brilliant, higher lying region in the southern hemisphere; the second, at least 10,000 feet lower, consists of the floors of the maria; the third, again 10,000 feet deeper, corresponds to the bottoms of the circular craters which have been formed within the maria after their con-

solidation. On the other hand, Brown[18] has determined that the higher, southern limb is farther from the moon's center of mass than the northern. In other words, the principle of isostasy applies to the moon. There seems, then, to be sufficient analogy between the moon's maria and the earth's ocean basins for the former to give testimony in regard to the causes that have operated to make the latter.

There are several ways of determining the relative ages of the features on the moon's surface. The most positive time value is the order of superposition of craters. Next to be noted is the fact that the older craters have lower-angled slopes, as shown by the deficiency of shadows cast by the slanting sunlight. The younger craters, showing their youth by their sharpness of definition, as well as by superposition, also have the ray systems that are so conspicuous under the high-angle light upon the full moon, as seen in Plate 1. The maria, on the other hand, are younger than the chaotic upland surface, as shown by the melting in of that surface and the absence of ancient ruined craters. Some of the craters on the margins of the maria are, however, partly melted relics of the older surface, but most of them are clearly younger than the lava plains. The great crater Copernicus (near the top of pl. 3) is conspicuous among these younger features, but in the older area of the moon there are craters just as young, as seen in Tycho (near the center of pl. 2), which has the most conspicuous ray system on the moon.

Do all the physical features of the moon belong to a period early in its history; is it now a dead world? This is the view commonly taught by astronomers and it has been accepted by geologists. Interpreting the moon's surface features by the methods of geology, however, a quite different answer is obtained. Its internal igneous forces work too slowly and intermittently to be seen by the human eye, unless such small changes as those observed in the crater Linné are indeed the result of recent igneous activity.

The measure of the relative recency of events may be obtained from a study of the progress of crumbling recorded on the walls of the craters. In terrestrial deserts the chief causes of disruption of the rocks are (1) rapid change of temperature from night to day, (2) freezing of water in joints, and (3) dashes of rain on heated rocks. On the moon, however, rain is wholly absent, freezing in joints may be a minor factor from volcanic waters; but the changes of temperature between midnight and midday, though slower between maxima, are rapid at sunrise and sunset and the results are far more profound than in the earth's deserts. During the lunar night, the tem-

[18] E. W. Brown, Address on Cosmical Physics. British Association, sec. A, Australia, 1914. Reference No. 201, p. 6.

perature of the surface, which is not blanketed as on the earth by an atmosphere, must sink to near absolute zero. But the night endures for two weeks, and in this time cold and resultant contraction must penetrate many feet in depth. During the two weeks of lunar midday the temperature of the moon's surface in its torrid zone has been measured as being above the boiling point of water on the earth. This rhythmic monthly change of temperature of perhaps 500° F. must have somewhat the same disintegrative effect as the exposure of rocks to fire. Blocks large enough to be cold on the inside while hot outside, and vice versa, will be riven by the rhythmic expansive and contractive forces. The recurrent changes in volume must tend, therefore, to work the loose material down to flatter and flatter slopes, although the individual fragments will still stand up with steep faces. There are, however, limits to these actions, dependent upon the rapidity as well as the amount of the temperature changes. This form of insolative disintegration, dependent upon solar heat, has been operative with nearly equable effect throughout the whole history of the moon and has been most intense in its equatorial latitudes. It may be further aided by the passage of lunar heat and gases at times of exceptional volcanic activity, but the evenness of the disintegrative effect suggests a dominance of external temperature changes as the cause. Craters which show no appreciable insolative disintegration are therefore relatively young. From these sharp-edged craters we may trace back successive generations in time until, as in the region of Tycho, may be faintly seen the almost obliterated ruins of great crater rings that appear to be twenty or even one hundred times older. Measured by the scale of terrestrial chronology, the great craters Tycho and Copernicus, each 65 miles in diameter, may be as recent at least as the younger Tertiary.

Judged by these means, how old are the maria? Here we must decide between the craters that are within or adjacent to the maria, but are older than they, and the craters that are younger. The outer portions of the Mare Nectaris[19] show an ancient topography, but the bounding scarp of the Altai Mountains at the edge of this mare is very high and steep. The floor of Nectaris appears, consequently, to have been formed by a downsettling accompanied by a melting in, but the latter process has not extended to the walls. The great crater Theophilus situated in this mare is, however, younger than the mare, as shown by the depression of its floor, but it is without the ray system, which appears to mark the very youngest of the craters. Thus we reach the striking conclusion that the maria are among the younger features of the moon, though not the youngest.

---

[19] The small mare in the southwest quadrant nearest to the center. In pl. 1 the features spoken of do not show.

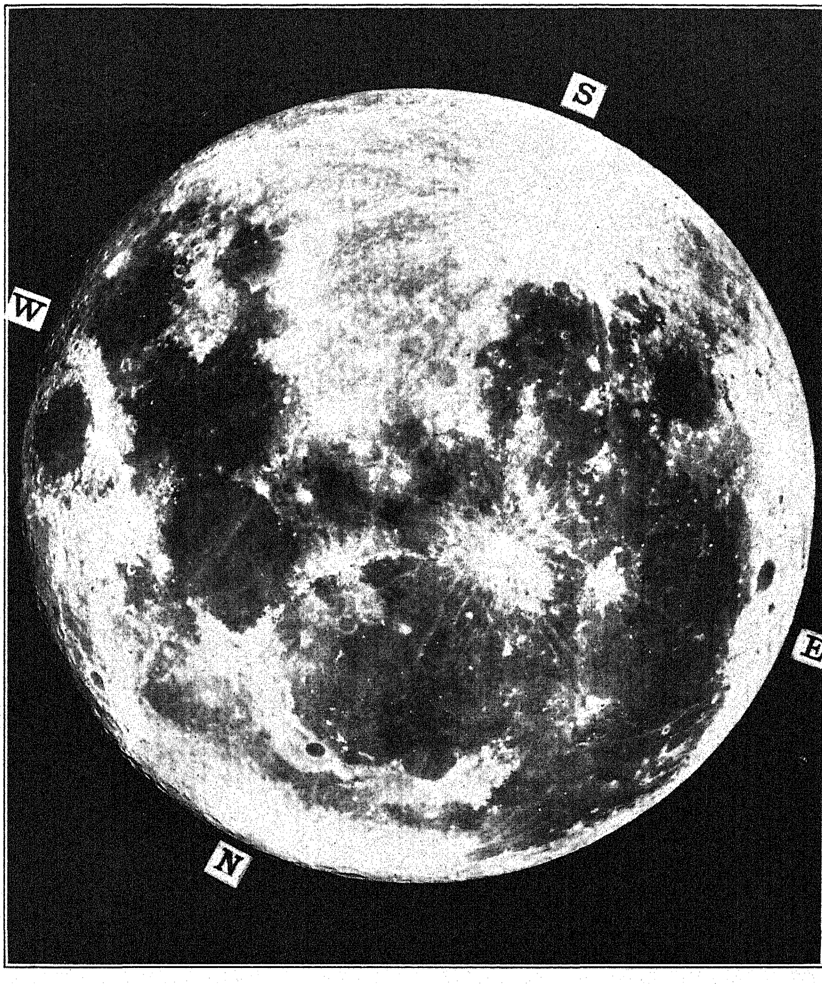
The craters resemble in form those of the Hawaiian Islands. They appear to have been opened by gaseous drilling from below, as are terrestrial craters, and by final explosive outrushes of gas rising through pipes filled with lava or breccia, but for some reason the igneous forces in the moon lack the power to produce extensive overflows. On the other hand, the alignment of small craters, as those on the left of Copernicus, shows that they are not, as some have surmised, the results of impact from the outside during the original formation of the moon.

Although craters of all sizes may be noted in the moon from the minute craterlets to the great maria, the latter appear to represent a different kind of activity. Within the Mare Imbrium there are remnants of a ring outlining an older and smaller feature. The older, rough topography of the floor of the mare flattens and fades out by degrees. To understand this feature, imagine a rough surface of pitch, with an outer temperature far below 0° F., heated from below until the interior became fluid, the outer skin remaining cold and solid, but the supporting layer passing into a soft and viscous state. The relief would therefore flatten down, but not be absolutely lost. Such appears to be the most instructive analogy for the interpretation of the surfaces of the maria, although in places thinly fluid lava may have overflowed.

The craters probably are gas vents, and are instructive, by analogy, in regard to the continued supply and internal origin of the terrestrial atmosphere and hydrosphere. The maria seem to represent the culminating rise of magma from the depths into the outer crust at long intervals of time, accompanied by a melting in of the covers, and correspond to the broad batholiths exposed on the earth by erosion.

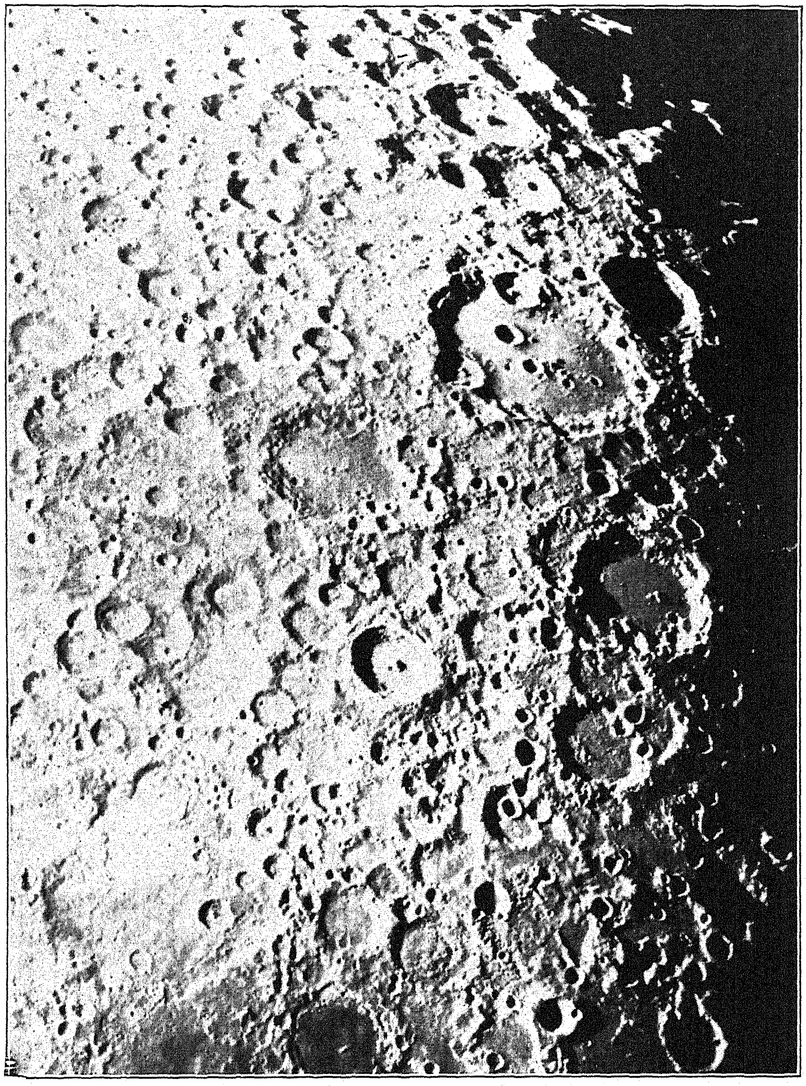
We are now prepared to compare instructively the maria of the moon with the ocean basins of the earth. The great lava plain on the east side of the moon corresponds rudely to the Atlantic Ocean; the embayments on the south may be likened in form to the Gulf of Mexico and the Caribbean Sea; the coalescent maria on the west, Serenitatis, Tranquilitatis, Fecunditatis, and Nectaris, to the chain of Mediterranean deeps; the isolated Mare Crisium in the northwest to the similarly isolated basin of the Black Sea. The uplands occupy the lesser portion of the surface, extend into the angles between the maria, and in places are seen to fault off and subside into them. These resemblances to earth characters also caught the eye of Galileo and led him to regard the lava floors as in reality lunar seas.

Thus the study of the earth's small sister planet supports the general hypotheses that the ocean waters as well as the ocean basins have arisen through igneous activity, and that fragmentation of the original crust has dominated the moon as well as the earth throughout geological time.



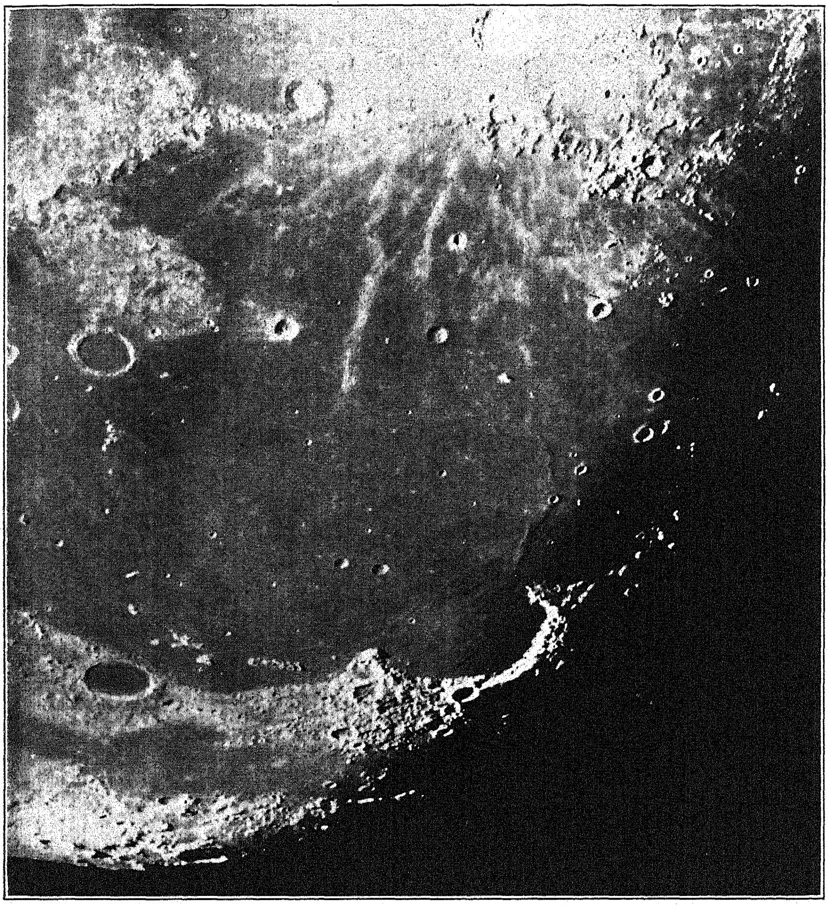
THE FULL MOON

In the telescope the directions are reversed, south appearing above and north below. The maria are the dark plains covering about half of the hemisphere. The Mare Imbrium is seen as a great circular plain, over 600 miles in diameter, in the northeast quadrant. To the left of it lie the Maria Serenitatis, Tranquilitatis, and Fecunditatis in order. Below the last is the isolated Mare Crisium. Just south of Imbrium the large brilliant spot with irregular rays is the crater Copernicus. To the south of Copernicus is the Mare Nubium. Still farther south is the crater Tycho, from which radiates the most brilliant ray system of the moon. One ray may be traced across the Mare Serenitatis, fully one-third of the way around the globe. These ray systems give a pattern of intersecting lines somewhat similar to the "canal" systems of Mars, but here on the moon are clearly developed by purely physical actions. (Photograph by Yerkes Observatory)



A PORTION OF THE SOUTHERN HEMISPHERE OF THE MOON

A little below the center is the crater Tycho, 65 miles in diameter, distinguished by its sharp rim and central cone. Above and to the right is the large crater Clavius, 142 miles in diameter. Its greater age is shown by its crumbled walls and the number of younger, sharply defined craters superimposed upon its bottom and wall. Below, at the extreme north, is seen the margin of the Mare Nubium. (Photograph by Yerkes Observatory)



THE MARE IMBRIUM AND ITS SURROUNDINGS, NORTHEAST QUADRANT OF THE MOON

The floor of the mare is seen to be older than the ray system of Copernicus and the small, sharp-lipped craters scattered over it. The mare is younger, however, than the rough topography within its walls on the left. On the northern (lower) border of Imbrium is seen the crater Plato, 60 miles in diameter and with crater walls 4,000 feet high. It is flooded by lava which appears to be related to that of the mare. On the right, near the sunrise line, is preserved the half of a still larger circle, opening into the mare and forming the Sinus Iridum. (Photograph by Yerkes Observatory)

THE "CRATERS OF THE MOON" IN IDAHO[1]

By Harold T. Stearns

[With four plates]

When in recent geological time the glaciers began to melt away from the towering peaks of Idaho, floods of lava poured out of a fissure on the south side of the White Knob Mountains. The cooled and weathered products of these eruptions now form the unique volcanic area known as the "Craters of the Moon" which was proclaimed a national monument by President Coolidge on May 2, 1924. It is reached by a drive of 26 miles from Arco southwest along the Idaho Central Highway, and is easily accessible to visitors en route for Yellowstone National Park. Upon entering the monument the road leaves the dusty sagebrush desert for an area of barren black cinders and lava, where it winds among smooth cones and across strips of rough, fresh-looking rock. The similarity of the dark craters, and the cold lava nearly destitute of vegetation, to the surface of the moon as seen through a telescope gives to these peculiar features their name. The monument comprises 80 square miles of the most interesting and recent part of a vast lava field which covers hundreds of square miles and merges westward into the Columbia Plateau. This plateau covers about 200,000 square miles and is probably the largest lava plateau in the world.

A good view is obtained from the summit of Big Cinder Butte, which rises to an elevation of 6,516 feet and ranks among the largest purely basaltic cinder cones of the world. To the east stretches barren black lava with nothing to break its monotony except one group of yellow grass-covered cones which were not inundated by the floods of lava, and which now stand together as a yellow island in a sea of black. Farther east rises Big Butte, the sentinel of the Snake River Desert. A little beyond and to the northeast of it are two small peaks known as the Twin Buttes.

To the southeast extends a double line of cinder cones, many of them grass covered, and all of them vents of numerous flows which

[1] A note prepared in cooperation with the Idaho Bureau of Mines and Geology, and published with permission of the Director, U. S. Geological Survey, in the Geographical Journal, Vol. LXXI, No. 1, January, 1928, London. Here reprinted, by permission, from that Journal, with slight alterations.

unite southward into one great field of lava, lonely and uninhabited. Black Top Butte, the farthest in this march of cones, lies approximately 11 miles southeast of Big Cinder Butte. Still farther away are yellow grass-covered cones, and in the distance are barely discernible the snow-covered Portneuf and Bannock Mountains. Four miles to the south lies a chaos of cinder crags and jagged lava surrounding a high cinder cone called North Laidlow Butte. Half a mile beyond this cone is Little Laidlow Park, a grass-covered field of ancient lava, appearing pale yellow under the bright desert sun of midday. Farther away on the plain are low lava domes, and in the far distance beyond the Snake River are pale blue mountains along the Idaho-Utah line.

To the west for about 6 miles the lava has flowed against the southern spur of the White Knob Mountains, filling the valleys as if they were bays and leaving the ridges like projecting headlands in a black sea. To the northwest there are crater pits, spatter cones, cinder cones, and lava flows massed along the Great Rift. Many of the cinder cones are brilliant red at noon, but slowly change to purple with sundown. On the tops of many of them are crater pits which are especially beautiful under the lengthened purple shadows of evening. Beyond these features rise the granitic White Knob Mountains covered with grass and streaked with small groves of aspen in the twisted ravines and canyons. Farther northward are the snow-clad Sawtooth Mountains.

Before any lava had appeared in southeastern Idaho, the White Knob Mountains of granitic rocks, then higher, projected southward into the wide open valley of the ancestral Snake River. All the rivers—Big Lost River, Little Lost River, Birch Creek, and all the other streams adjacent to the area—flowed southward from the mountain canyons and joined the ancient Snake. To-day these rivers sink into the lava plain at the foot of the mountains and find their way underground into the Snake River through numerous crevices and cavities in the lava.

The White Knob Mountains and their foothills were undisturbed except by stream erosion until a fissure called the Great Rift opened on their slope. With this earth rifting there occurred an eruption that built up a long line of cinder cones, and lava flowed southward and eastward, cooling into thick jagged flows consisting largely of broken blocks. Frozen in some of these lava blocks one can find both large and small fragments of granodiorite that were stoped off from the roof of the lava reservoir and floated upward in the molten lava during the eruption. The lava must have issued at a temperature of about 1,200° C., which was too low to remelt the granitic inclusions; hence the white fragments retain all their original characteristics. Numerous eruptions occurred during this

epoch, and most of the flows and cones are now buried by later flows. Remnants of these old cones, broken by faulting and weathered down into hoodoolike pinnacles of cinders and spatter, form the Devil's Orchard, and the field of crags south of Big Cinder Butte. In these crags occurs obsidian, or volcanic glass, which the Indians quarried to make arrow points and other implements of stone.

For a long time the Great Rift seemed to be healed, but volcanic activity broke out again with renewed vigor, and many of the large cinder cones in the chain that stretches southeast through the center of the monument were formed. To this second epoch belong Sunset, Grassy, Silent, Big Cinder, Fissure, Split, and numerous unnamed cones along the Great Rift. Most of their lava flows have been buried by later flows, but the cones rise as islands above them. The volcanic outbursts were spasmodic but probably followed at short intervals. Often more than one cone was formed during a great eruption, and there is evidence that some of the cones were made by successive eruptions occurring at the same place.

The third and last epoch of eruption followed closely upon the second and may have been actually closely connected. During this epoch, which is the most recent, all the barren black lavas that are found in the area were emitted. North Crater, visible from the road to Carey, was reopened and gave vent to a large billowy lava flow that moved northward and then eastward. This flow is crossed by the road leading to the registration booth. Big Crater gave vent to four flows during this epoch, to the northeast, northwest, and southeast. With the last eruption of Big Crater the line of spatter cones at the end of the motor road was formed and lava flowed east and west from them. With the subsidence of the lava in the Great Rift following this eruption numerous areas along the rift collapsed, forming a chain of pit craters. Big Sink water hole is located in one of these pit craters. Big Cinder Butte broke open again and gave vent to a short lava flow on the north side. Two other outpourings of lava occurred in the area one half-mile northwest of this breach, but the eruptions at these vents did not build cinder cones. Lava also poured out at Indian Tunnel, the Natural Bridge, and at Needles Cave in the area east of Inferno. In the central part of the monument the old cinder cone called the Watchman opened and lava flowed out quietly from the northwest and the southwest sides. Altogether 35 cones and vents and 30 different lava flows of various epochs are found in the monument, and many others are probably buried.

No evidence was found of any great explosive eruption such as occurred at Krakatoa in 1883, or at Katmai in 1912. The volcanic

outbreaks in the monument were all of the so-called quiet type and similar to those that occur at intervals at Kilauea and Mauna Loa.

Many kinds of lava have been poured out on the surface of the earth, but they all fall into three main classes or types. The first type of lava, rhyolite, or the iron-poor lava rich in silica, is the common lava of Yellowstone Park which gives the Grand Canyon of the Yellowstone River its magnificent colors. The second type, andesite, contains moderate amounts of both iron and silica, is usually gray in color, and forms a considerable part of the volcano of Lassen Peak, Calif. The third type, basalt, rich in iron but poor in silica, covers the Snake River Plains, forms the rim rock along the Snake River, and is the only type of lava occurring in the Craters of the Moon.

Two distinct physical types of lava flows occur here. Pahoehoe, the billowy, ropy type of lava that is filled with caverns, covers about half the area. Its shiny, blue, glassy crust makes some of the flows extremely beautiful in brilliant sunlight. Its wrinkled surface is due to the cooling of a thin crust or scum on the flow while the crust is being pushed forward by the lava below. The numerous caverns that are found in the Craters of the Moon all occur in this lava. As the flow continues the surface and sides solidify, and a tube is formed which forks and reforks as the flow moves out over the plain. Thus the lava is conducted without much loss of heat to the advancing margin of the flow, and as the slope of the land is not very steep, only the upper or source ends of the tubes were drained when the lava ceased flowing. Indian Tunnel, Owl Cavern, and Buffalo Cave show lava stalactites formed by the dripping of the lava from the roof. The narrow ledges parallel to the floor of the caverns are the shore lines of a subsiding river of lava. On the floor the last stream of lava with its ropy and twisted surface is usually visible. When the lava drains away, many portions of the roof fall in or are shaken down by earthquakes accompanying later eruptions. The natural bridges and caverns are shorter or longer roofed-in portions of the tunnel.

The other physical type of lava flow in the monument is the rough, bristling, jagged a-a lava, chemically the same as the pahoehoe lava. Its origin has not yet been definitely determined but it appears to be due to losses in heat and gas, and to amorphous glassiness. The lava is in a pasty condition while in motion and continually produces this broken, jumbled material by the cooling and breaking of the crust. Some of the fragments are pushed and rolled at the margin of the flow and others are dragged along under the lava. The whole flow resembles slush ice in a river in the spring. A-a lava flows 50 to 100 feet thick are found in the monument many miles out on the plain.

There are three distinct types of cones in the area—cinder, spatter, and lava cones. The cinder cones, with black, loose, cindery surfaces and smooth conical profiles, are the heaps of lava froth or spray formed at the time of eruptions. Big Cinder Butte is the finest example in the area. Spatter cones are formed when the clots of lava hurled out were insufficiently inflated with gas to form cinders and moved so slowly and for so short a distance that they fell as clots in a viscous state and adhered to each other, building up rather steep-sided cones of small height and diameter. The line of spatter cones southeast of the end of the motor road, all less than 50 feet high and 100 feet in diameter, is one of the most perfect in the world. The third type of cone found in the Craters of the Moon is the lava cone or dome. Lava domes consist entirely of lava and are broad and flat, and sometimes surmounted by tiny spatter cones less than 10 feet high. These inconspicuous domes are formed by the quiet and continuous welling out of pahoehoe lava, and as most of the lava escapes through tubes the cones are not high, often only 30 to 50 feet. Owl Cavern, Indian Tunnel, and Surprise Cave mark sites of lava domes.

A curious feature found in the monument are the lava bombs scattered on the cinder and spatter cones. These bombs vary in length from one-half inch to over 13 feet, and in diameter from one-fourth inch to 3 feet. There are three types—spindle, ribbon, and bread-crust bombs. Spindle bombs, which have earlike projections on the ends of a football shaped body, were clots of lava which were hurled through the air with a rotational motion. The best formed bombs are found close to their source. The ribbon bombs are the long tapering twisted ears that project 3 to 10 inches from the ends of the spindle bomb. These long thin strips of lava were broken off by the fall of the projectile and lie scattered on the surface. Some were formed by the pulling apart of two clots of lava traveling at slightly different speeds or in slightly different directions. The long ribbon bombs, 2 to 13 feet in length and a few inches wide, seem to have originated in one of two ways. A few are lava clots that fell on the side of a cone, ran down the slope while still molten, and were later detached by weathering, and the removal of the adjacent cinders. Other ribbon bombs are formed by the throwing out from a spatter or cinder cone of a large clot of very liquid lava that stretches out during its flight and falls on cinders sufficiently loose to prevent its breaking. A third kind of bombs are light and porous and covered with a skin resembling bread crust. They are formed by a clot of lava filled with gas being hurled through the air. During its flight the crust cools, and as the gases expand the hard skin is cracked open in numerous places.

Tree molds exist in certain flows in the Craters of the Moon where the lava flowed slowly and at the right temperature into a forest. The molds vary in diameter from a few inches to 3 feet, and are easily distinguished from other holes in the lava. Many of them are 10 to 20 feet in depth. Molten lava does not completely destroy a tree because a few inches of solid lava crust prevents any great amount of heat from escaping through it, and liquid lava at or near the cooling point requires very little time to solidify into a poor heat-conducting shell around the tree. While the tree is burning it shrinks away from the surrounding lava, creating an air space or chamber between the tree and the mold which accelerates the cooling. The process is further aided by the steam from the sap of the tree. There is much less chance of the formation of a mold from a dead tree, for it burns too rapidly. The writer saw in Hawaii two years after the eruption trees only partly buried by lava with their upper portions uncharred and dead leaves clinging to the branches.

Most of the vertical tree molds do not preserve any charcoal impressions, but where the tops of the trees fell on plastic lava the mold of the charred log and the grain of the wood is sometimes preserved. In places the lava was soft enough or rendered sufficiently plastic by the steam from the burning wood to flow into the shrinkage cracks in the charred surface of the log, forming a checker pattern easily mistaken for bark impressions. No tree mold showing bark impressions was found in the monument.

One kind of tree mold, called lava trees, is common on Trench Mortar Flat southeast of Big Cinder Butte. These trees rise 1 to 5 feet above the lava surface and were formed in the same manner as the tree molds, except they were in places from which part of the lava flow could drain away, or else they were buried by spatter from a spatter vent.

Ice-cold water is found even on hot July days in the most unexpected places, its temperature rarely exceeding 2° F. above freezing. Most of the large water holes occur in depressions in very rough broken lava, where much snow collects in the winter. Some of it sifts down into the crevices between the rocks and remains sheltered during the summer days. Water during the thaws may drip downward into the crevices where it is frozen by cold circulating air. Some melts in the summer, but in favored positions it never entirely melts away, as the lava is a poor conductor of heat. If one digs down into the loose rock in a water hole of this type ice will always be found beneath the water.

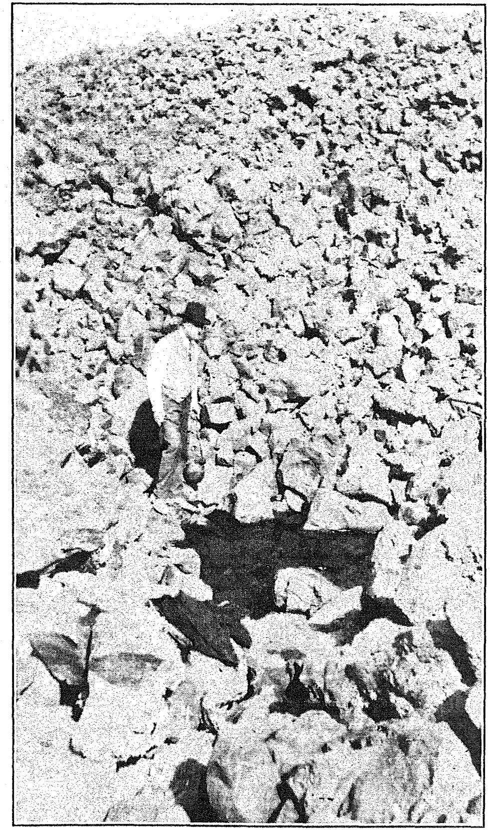
Water and ice occur also in the lava caves or tubes where draughts of cold air freeze any water that percolates into them. This occurs about seven months in the year, and during the remaining months

there is a gradual wasting away of the ice, but melting proceeds slowly, as even during the summer the temperature of the interior of the caves does not rise above 40° F. Ice and water are found also in the deep inverted funnel-shaped craters of the spatter cones. The snow accumulates in the crater during the winter and is exposed to the direct rays of the sun for only a short time each day. Thus there results a continually increasing heap of ice which, in the Ice Cave near the end of the motor road, is about 20 feet thick.

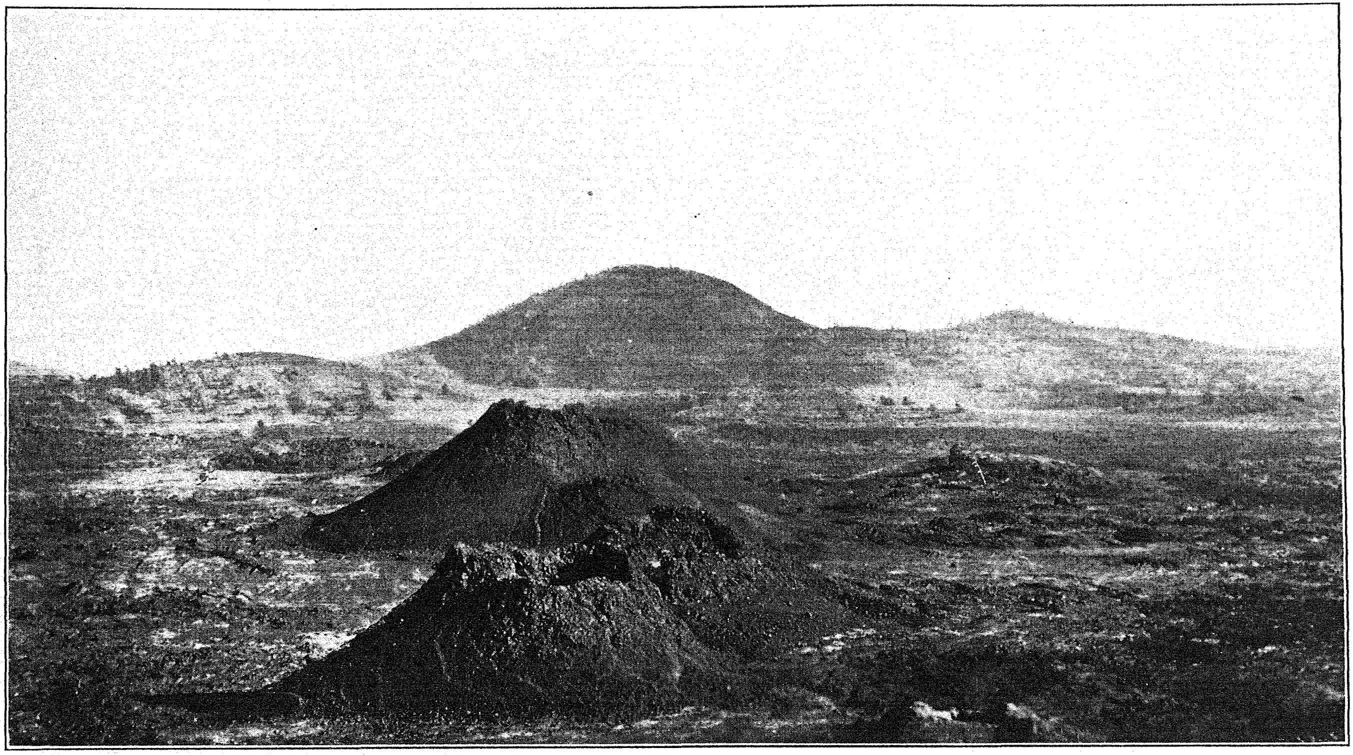
Ice Caves do not occur anywhere in the world except where there are freezing temperatures during some part of the year. On the active volcano of Kilauea, Hawaii, where thousands of similar caves occur and where much rain falls, no ice occurs in the caves. The explanation of this is apparent, for no snow falls nor do freezing temperatures occur during the year. Mauna Loa Volcano, which rises nearly 14,000 feet above the sea into the snow zone, contains numerous ice caves in and near the crater, and many are found only a stone's throw from a steam vent. The lava in the Craters of the Moon is so fissured that no water is found in it throughout the year except where it lies upon an impermeable body of ice.

Despite the freshness and bareness of the black lava, the longer one studies them the more one realizes the time that must have elapsed since the last eruption. The absence of the soil on many of the flows is easily accounted for. All the fine dust is blown away or into near-by cracks. This hidden soil accounts for the numerous shrubs and pines that grow in the crevices where no soil is visible. The vegetation has about a four months' growing season and is poorly adapted to its environment. The writer found a pine growing in a crack in the Big Crater lava flow, a flow that appears as black and recent as any in the monument. This tree has fresh black lava of the Big Crater flow actually touching the trunk two feet above the base of the tree, and the tongue of pahoehoe in which the tree grows is split open and wedged apart by the roots of the tree. This tree is 33 inches in diameter and has been dead only two or three years, having been killed by lightning. It is perfectly sound and shows no burning scars nor any indications of fire. Counting the annular rings of this tree shows that it was 461 years old. Other larger trees can be found rotting on the lava surface that have been dead at least 100 years. The lava was certainly extruded before these trees came into existence.

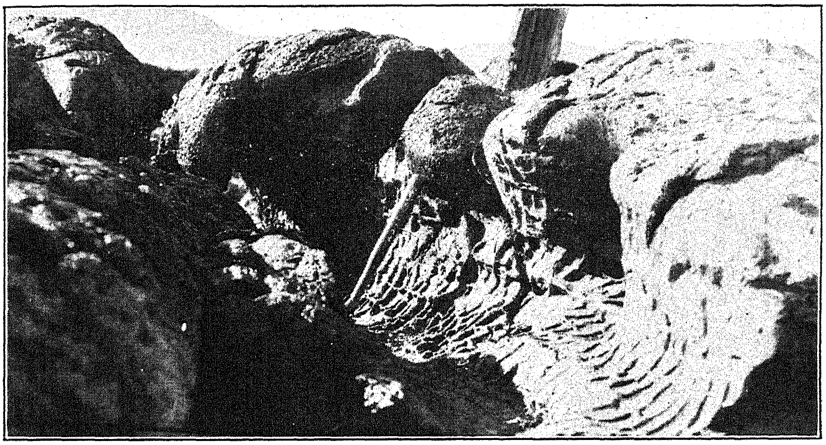
1. Surface of Pahoehoe Lava Flow



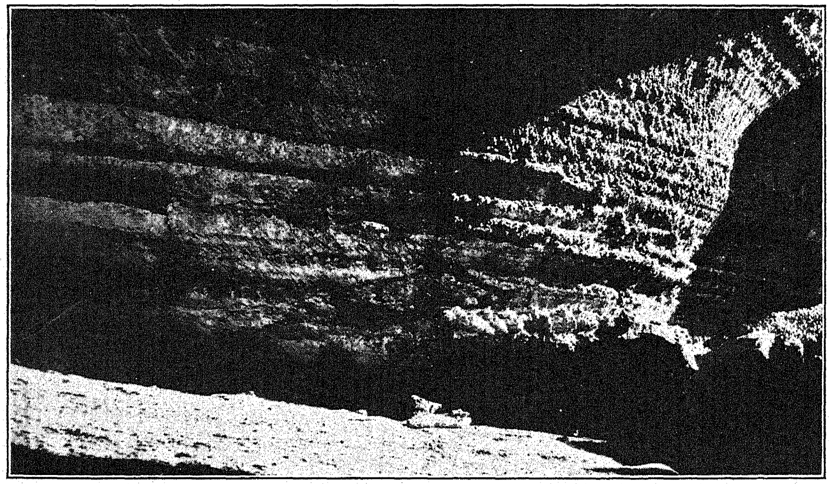
2. Hoodoo Water Hole in Loose Blocks of Lava



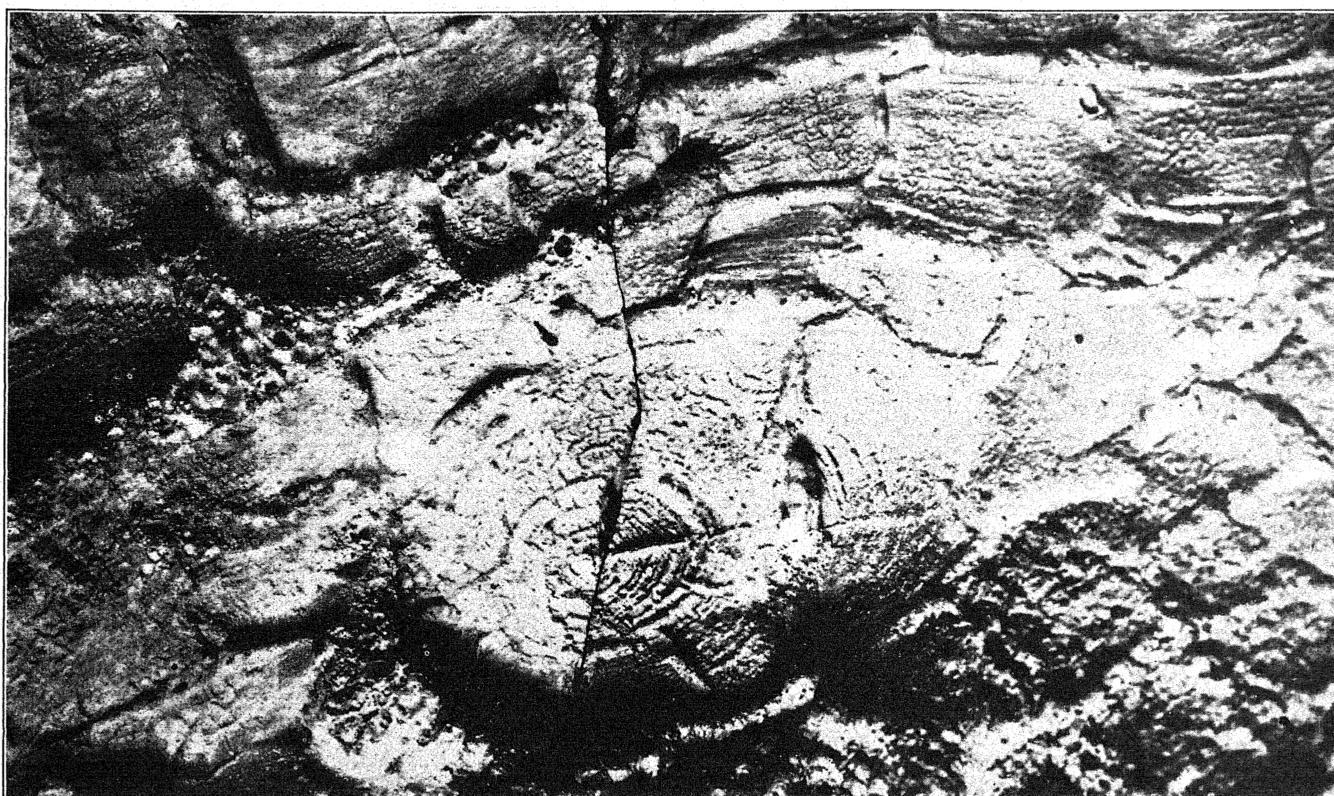
CHAIN OF SPATTER CONES ALONG THE GREAT RIFT



1. IMPRESSION OF CHARRED LOG IN LAVA



2. LEDGES MARKING LEVELS OF LAVA, BUFFALO CAVE



CLOSE-UP VIEW OF IMPRESSION OF CHARRED WOOD IN LAVA. NATURAL SIZE

THE OLDEST KNOWN PETRIFIED FOREST[1]

By Winifred Goldring
New York State Museum, Albany, N. Y.

[With nine plates]

Dreams do come true—sometimes; and one of the most recent dreams of the New York State Museum was realized when, on February 12, 1925, there was formally opened to the public the restoration (see pl. 1) of the extensive forests that flourished in eastern New York a few hundred million years ago during Upper Devonian (Ithaca) times. The history of the discovery of these trees and the gradual accumulation of material which led to the final solution of their nature is almost as interesting as the ancient trees themselves.

HISTORY OF DISCOVERIES

Back in 1869, over half a century ago, the little village of Gilboa in the Catskills (Schoharie County) came suddenly into prominence from a paleobotanical point of view. In the autumn of that year the upper valley of the Schoharie Creek was swept by a great freshet which tore out bridges, culverts, and roadbeds around the little village of Gilboa. But science, at least, has much for which to be grateful, for at the same time that all this disaster was caused the freshet very obligingly exposed in the bed rock along the creek standing stumps of fossil trees, all at the same level. The discovery of these trees was described in the Albany Argus of January 30, 1870, and in the twenty-fourth Museum Report (1872, for 1870); and it was considered of so much importance that it was brought by Professor Hall to the attention of the British Association for the Advancement of Science in 1872. Excavations were made during the year 1870 in the bed of sandstone containing these trees and five stumps and a number of fragments were taken out of this ancient forest. The greater part of this material was brought to the State museum, where it has for some time constituted a remarkable exhibit of the ancient, extinct flora of the State.

---

[1] Reprinted by permission, with slight changes in the illustrations, from the Scientific Monthly, Vol. XXIV, pp. 514–529, June, 1927.

The Gilboa collections were submitted for examination to Sir William Dawson, of Montreal, then principal of McGill College, and in his day an authority on the plants of the Devonian. Dawson placed these trees in a genus of true ferns, represented by trees, and distinguished two species, *Psaronius textilis* and *P. erianus*. The genus has in these later years been thoroughly studied; and it has been found that the structure is quite different from that of the Gilboa trees. Moreover, *Psaronius* belongs to the Carboniferous, the period of our coal trees, and is much more recent by millions of years than these Upper Devonian trees. The problem of the nature and relationship of our Gilboa trees was still left to science, and seemed incapable of solution until the summer of 1920.

It had always been assumed that our Devonian trees had a scattered distribution—no one dreamed of a vast and extensive forest. The old locality had long since been covered up and the rocks at the level in which the trees were discovered did not outcrop again in this area. Nothing more was heard of these fossil stumps until in 1897, when Prof. C. S. Prosser, then connected with the New York State Survey, reported finding some small specimens, from a higher horizon, lying loose at the Manorkill Falls about a mile above Gilboa. Occasional attempts since then to relocate this primeval forest of the Devonian period were fruitless until the summer of 1920, when special effort was made to add to the collection of Devonian plant material already in the hands of the museum. In this year the efforts to relocate the Schoharie forest or to find some additional evidence as to its extent led to the discovery of upright tree stumps not in the original locality but 6,400 feet south, at the higher level along the road in the vicinity of the lower falls of the Manorkill, tributary to the Schoharie Creek. (See pl. 4, fig. 2.) Five specimens were taken from this site. These trees, as was the case with those first discovered, were found with their bases resting in a bed of shale, black or greenish-black in color, and representing the original mud in which the trees grew. This tree locality, which constitutes the highest horizon in which these stumps have been found, has an elevation of 1,120 feet above tide, and when the Gilboa Reservoir is filled the flow line will be some feet above this spot. The old locality, on the same side of the Schoharie just above the old Gilboa bridge, had an elevation of 1,020 feet A. T., giving a difference of just 100 feet between these two tree horizons. Since 1920, the city of New York has been doing construction work at Gilboa, preparatory to impounding the waters of the Schoharie Creek for the future use of its citizens. The resultant reservoir will extend over a length of nearly 7 miles and will drown the village of Gilboa and its vicinity, including the two above-mentioned fossil-tree localities. In 1921, in the course of quarrying in connection with the work on the dam, the old locality, which is

directly at the spot where the dam was being built, was uncovered and seven stumps were found, some of them too badly broken to permit removal. One specimen taken weighs nearly a ton and has a circumference of nearly 12 feet (diameter about 4 feet). In a quarry about half a mile (2,300 feet) downstream from the old locality, trees were found at a level of 960 feet above tide, 60 feet below the oldest or middle locality, 160 feet below the highest level where trees were found . This quarry, known as "Riverside Quarry" (see pl. 3, fig. 2, and pl. 4, fig. 1), has yielded the greatest number and also, on the whole, the largest stumps found. During one period 18 specimens were taken from an area 50 feet square, not counting those destroyed in quarrying. One of the largest specimens of this group has a circumference at the base of approximately 11 feet (diameter approximately 3.5 feet), a height of 22 inches, and a diameter at that height of 21½ inches; stumps of greater height, but of smaller girth, have been obtained. At all the three tree horizons the stumps were found with their bases resting in and upon shale and in every case in an upright position with the trunk extending into the coarse sandstone above. The shale beds representing the muds in which the trees stood vary in thickness from 6 inches to 2 feet, more often thin than thick.

By the spring of 1924 with the additions to our collection, which we owe to the courtesy of the commissioners of the New York Board of Water Supply and the various engineers connected with the work, we had in our museum a total of nearly 40 stumps, partial or complete, and a number of broken pieces. We have not added to our number of fossil trees since then; but they have been distributed among various museums and some even have gone into private hands. Taking into consideration with all these, those still at the quarry, the weathered stumps discarded, and those destroyed in quarrying, the number of stumps taken from these primeval forests must run into the hundreds, and continued quarrying will bring more to light. Riverside Quarry is not included in the area covered by the Gilboa reservoir, but its value as a fossil tree locality will be greatly lessened with the cessation of quarrying operations. Now that the rock layers containing the stumps have been located, it is quite possible that they can be traced around the hills and found outcropping elsewhere. In the area known, the tree localities have been found stretching over a distance of something more than a mile and two thirds. No forest as old and as extensive as this has anywhere been reported up to date. We therefore have in eastern New York, up to date, the oldest known forest in the world, and in our museum a unique and unmatchable exhibit.

Except for the discovery of the seeds, which was quite accidental as many very important discoveries are, we would still have been

left with a forest of fossil stumps and have been little better off than were Professors Hall and Dawson in 1869. By the merest chance, Dr. Rudolf Ruedemann, State paleontologist, who was on the ground with some other collectors in the summer of 1920, came across a slab of dark shale containing seeds along the edge of the Schoharie Creek in the vicinity of the Manorkill Falls. (See pl. 3, fig. 1.) The slab was traced to the bed of shale from which it was derived and a number of good specimens were obtained. Later in that summer the writer and an assistant worked this bed of shale and a fairly large collection of excellent material was obtained, including not only the seeds, but another kind of fruiting body, bits of foliage and roots. Further efforts in the summer of 1923 led to the discovery of a new locality about 30 feet south of the original exposure, and in this and the following year our already unique collection was considerably augmented in both quantity and quality. Collecting in the spring of 1925 showed both localities to be practically exhausted, and besides this whole area will eventually be under the deep waters of the Gilboa reservoir.

In addition to stumps, portions of the trunks of these fossil trees were found in 1920 and later. In the early summer of 1923 bases of stumps were found in Riverside Quarry with the long, radiating straplike roots attached, so that there could no longer be any doubt that these trees grew *in situ*. In 1925 three specimens of the outer bark showing petiolar scars were brought in by Mr. R. Veenfliet, jr., a local collector. The greatest numbers of the trees comprising these ancient forests were of this Gilboa tree type, but evidences of two other kinds of trees have been found. One is a *Protolepidodendron*, a lycopodlike tree, similar to the Naples tree, *Protolepidodendron primaevum* (Rogers), known for so many years from the Portage beds of central New York. This tree has not yet been described. In the fall of 1925 two specimens of another type of tree with long, grasslike leaves on the trunk were collected in Riverside Quarry, and they have been described under the name *Sigillaria ? gilboensis* (N. Y. State Museum Bull. 267, 1926) as another lycopod type of tree.

In the early summer of that year a rootstock was found in the same quarry, which may belong to either of the last two mentioned types of trees.

2. UPPER DEVONIAN GEOGRAPHY AND PRESENT GEOLOGY

The Gilboa trees afford an index to the geography of the western Catskills and the Schoharie Valley during the late Devonian period to which they belong. During these times, the present Catskill Mountains formed the low shore line of a shallow sea; and the continental land lay off to the east of the Catskills, extending far into

the present area of the Atlantic. This shallow sea covered the interior of the State and country and received the heavy drainage from this eastern land mass. The southwesterly flowing rivers brought down débris of the primitive vegetation with which that lost land was wooded, and scattered the remains, leaves, stems, branches, etc., through the vast delta and shore deposits. Perhaps nowhere else in the known records of the rocks is there such an extraordinary accumulation of the land flora of this geological age as in these sands which underlie the slopes of the Catskills westward into the Allegheny Plateau. Plant remains were mingled with the earliest of the fresh-water mussels which burrowed in the sands of the river mouths; at times the rivers carried the forest growth far out among the marine deposits and it was mingled with the animal remains of the salt sea. This close intermixture of terrestrial and marine conditions is most abundantly shown in the lower or earlier part of the Catskill terrane. The coasts of those days were very unstable, which would give a swampy shore line. Forests of primitive trees grew along these shore lines, spreading down to the water's edge. Gradual submergence of the coast carried these trees beneath the water and the sediments piled up over their bases. At a later period when the sinking basin was again filled by deposits the forest again crept down to the water's edge. The discovery of these horizons of fossil tree stumps shows that three successive forests flourished here, were submerged, destroyed and buried. The fact that the stumps are buried in a fairly coarse sandstone indicates a rapid destruction and burial.

The geologic horizon of the occurrence of the Gilboa trees apparently is the Ithaca formation. The Oneonta is characterized by red beds and they are not found as low as any horizon containing tree stumps. Red beds characteristic of the Oneonta are seen a few feet above the highest tree horizon at the Manorkill. Collections made at a higher horizon four miles to the south at the intake of the tunnel show a prevailing Ithaca fauna; and it is therefore apparent that we have an intermingling of Ithaca and Oneonta sediments. The fresh-water unio, *Amnigenia catskillensis*, occurs in a massive sandstone one and a half miles northeast of Gilboa, some 600 feet above the level of the Schoharie Creek at Gilboa, which clearly indicates that the horizon of this shell is above that of the tree trunks found at Gilboa. The Ithaca fauna is also present on the hillsides above Gilboa; and all this indicates that we have in this area an interfingering of the Oneonta and Ithaca sediments.

3. STRUCTURE OF GILBOA TREES

A full, technical description of the Gilboa trees may be found in a previous article by the writer (N. Y. State Mus. Bull. 251, 1924, pp. 50–93) by those who care to go into more detail than is given in the following description.

The stumps taken from the three horizons show great variability in size and some variability in shape. (See pl. 5, figs. 1 and 2.) The bases of the stumps are bulbous, as might be expected of certain trees growing under swampy conditions, and show a circumference at the base from 3 feet and less up to nearly 12 feet (diameter less than 1 foot to nearly 4 feet). In general, the height at which the trunks were broken off varies from a few inches over 1 foot to about 3 feet or slightly over, but in the spring of 1925 a large specimen was taken from Riverside Quarry, which extended up into the trunk for 5½ feet. Some of the stumps narrow quite gradually from the bulbous base into the trunk, others very abruptly. The parts of trunk above the heights shown in the stumps, which have been found infrequently, are in a flattened condition. The museum has two of these specimens, one over 4 feet long and the other over 3 feet long. In the case of the latter, which was taken from the underside of an overhanging ledge, as much again of the trunk had been broken away and lost; and, beyond the section obtained, the trunk continued into the solid rocks with little, if any, diminution in width. Another specimen, too poor to be removed from the rock, showed some 12 feet of slender trunk which must represent a portion near the top of a large trunk or the trunk of a very small tree. Judging from the stumps and the portions of trunks, the largest of these trees must have reached heights of 30 to 40 feet.

The outer cortex is the only structure of the stumps and trunks of these trees that is to any extent preserved. The interior structures have been washed out and the cavity left filled with sand which has helped preserve the shape of the stumps in fossilization. The structure of the outer cortex is similar to that seen in a group of Carboniferous seedferns (*Lyginopteris*, *Heterangium*). It consists of interlacing strands of strengthening tissue (sclerenchyma), forming a network, or more or less parallel (see pl. 6, fig. 1). In transverse sections, unlike the Carboniferous forms, the sclerenchyma appears in the form of dots or short thick irregular lines, irregularly scattered. This zone of the outer cortex varies from an inch or less to several inches in thickness, depending upon the size of the stumps. In the majority of cases, the outside portion of the outer cortex is missing, but it is well shown in several cases. The outer surface is marked with shallow ridges and furrows, in some cases giving the effect of a bark; in other cases the outer surface is only irregularly

furrowed and wrinkled or even just roughened, some of which is undoubtedly due to shrinkage in preservation; but in either case the outer surface appears to be composed of layers of sclerenchyma forming a kind of bark, which in the living tree probably had a covering of ramentum or fibers. The underside of the base of the stumps (see pl. 6, fig. 2) is quite strikingly furrowed in a radiate manner, and in some specimens a depression is seen at the center. The base as well as the sides has the outer zone or covering of sclerenchyma layers above which is the zone several inches thick varying according to the size of the stumps, of interlacing sclerenchyma strands.

The interior structure of the trunk for the present remains unknown. A transverse section of one of the smaller trunks shows toward the center an irregular, thin ring of sclerenchyma tissue and within this ring and to some extent outside are irregularly scattered strands of sclerenchyma tissue. The scattered sclerenchyma strands may be due entirely to some maceration before preservation; but the ring itself appears to be a definite zone, part of a missing central cylinder of strengthening tissue. Transverse sections of larger trunks were made, but nothing was found. Success in this line can probably only be attained when a petiole or rachis of a frond is found preserved in such a condition that thin sections can be made for study.

In the earlier collections specimens of roots were found, but no stumps were taken with roots attached. This brought forth criticism of our statement that the stumps were buried *in situ*. The discovery in the spring and early summer of 1923 of specimens showing the underside of the tree bases with roots attached (see pl. 7) finally settled the question. The roots are long and straplike and radiate from the margin of the base. One specimen was obtained under difficulties and set up in concrete to form a museum exhibit, through the kindness of Mr. Henri Marchand, who was then working on the Gilboa restoration. The slab, as exhibited, measures 5 feet 7 inches by 6 feet 4 inches. The base of the stump is about 14 inches in diameter, and the radiating roots, from one-half inch or less in width to around an inch, extend without termination as far as the rock is preserved. From a study of this and other specimens it appears that the roots were undivided. Much larger specimens were found in the quarry with roots at least 9 feet long, but it was impracticable to get them out. The museum specimen is in sandstone, seen from the under side; but other specimens were found on the dumps some time later, showing the impression of the root base in the shale bed beneath the sandstone, often with the radiating roots well shown. The shale bed, as pointed out previously, represents the muds in which the trees grew.

The fronds of the Gilboa tree are compound, tripinnate (three divisions), and, judging from the fragments and larger specimens collected, were at least 6 to 9 feet long. (See pl. 8, figs. 1 and 2.) The pinnules were bilobed, with the lobes slightly recurved. The impression of the main rachis or stem of the frond in the widest part varies from three-eighths to five-eighths inch in the larger specimens. Both the primary and secondary divisions are alternately arranged. The petioles are described as slender and much expanded at the base and spirally arranged in about five ranks. Specimens of outer bark showing petiolar scars were collected in the summer of 1925, but as yet the museum has not located any specimens of trunks showing the attachment of the petioles. About 1870 or 1871 a Mr. Lockwood, of Gilboa, found the upper part of one of these trunks with its leaf scars preserved and petioles attached. The specimen was described by Sir William Dawson as probably the upper part of one or the other of his species of *Psaronius* found in the same bed.

The seeds of this Upper Devonian tree (see pl. 9) bear a strong external resemblance to those of the Carboniferous seed fern *Lyginopteris oldhamia* and to other Lyginopterid seeds. They were borne in pairs at the end of forked branchlets and were probably borne near the tip of the frond. Sometimes the dichotomies are such a short distance apart as to bring frequently two, sometimes three, pairs of seeds close together, giving a clustered effect to the seeds. The seed is broadly oval (measuring in the larger specimens 5.3 by 2.5 millimeters to 6.4 by 3.4 millimeters) and inclosed in an outer husk or cupule, which in some cases appears to be lobed. Separate nutlets were found. They occur in groups of small, rounded, thick bodies.

The second type of fruiting body found has been interpreted to be part of the male fructification, a sporangia-bearing organ (sporangiophore), though no separate sporangia have been found. These sporangia-bearing organs are modified pinnules; they are rounded-oval, saucer-shaped to funnel-shaped, and are borne on branching pedicels. It is believed that the sporangia were clustered and attached to the underside of the sporangiophore near the place of attachment of the pedicel and extending out toward the margin.

The two species described by Dawson were distinguished by the arrangement of the sclerenchyma strands of the outer cortex, which he interpreted as aerial roots; and to-day the species can stand only on those characters upon which they were originally separated, since we have discovered nothing further to add. His "*Psaronius*" *textilis* (pl. 5, fig. 1) is distinguished by a network of interlacing strands of sclerenchyma and "*Psaronius*" *erianus* (pl. 5, fig. 2) by more or less parallel strands. Only one kind of foliage has been found; also only one type of seed and male fructification. It would appear, then, that only in the internal structure of the trunks could these two

species of trees be distinguished while living; for if the two species differed in foliage and fructifications, with all the collections that have been made, some evidence of this would have come to light. There may, however, be another explanation of this. The fact that stumps of the *textilis* type have been found in numbers greatly in excess of those of the *erianus* type may account for the collection of only one kind of foliage and fructification, especially since the localities from which the collection of this material was made were few and of limited extent.

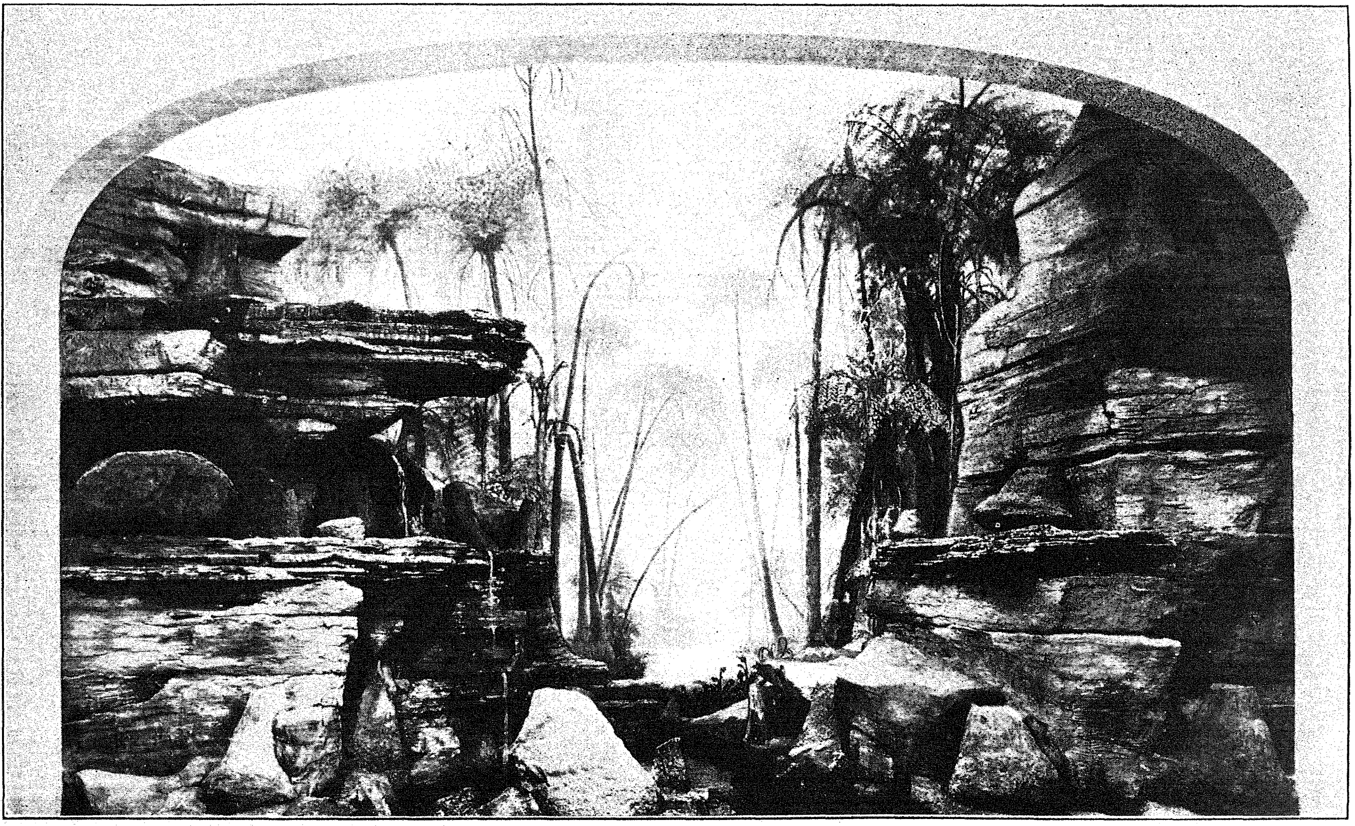
4. DESCRIPTION OF FORESTS AND RESTORATION

By June, 1922, after more than half a century since their first discovery, we were in a position to place our trees in their proper relationship and to attempt a restoration. These Gilboa trees in general appearance must have resembled the tree ferns of the Tropics to-day and also of the ancient Carboniferous and Upper Devonian times. The Gilboa trees, however, do not belong in this group; they were higher types (seed ferns or Pteridospermophytes), standing in a position between the tree ferns and higher seed plants, and they differ from the true ferns in the possession of seeds and in the higher organization of the trunk. Since the name *Psaronius* had to be abandoned for these seed ferns, a new genus was created, *Eospermatopteris*, meaning "dawn of the seed fern" (from the Greek: eos—*dawn;* sperma—*seed;* pteris—*fern*), and the two species now stand as *Eospermatopteris textilis* (Dawson) and *E. erianus* (Dawson).

As already pointed out, these trees grew along a low swampy shore. They probably reared themselves to heights of at least 25 to 40 feet and bore fronds at least 6 to 9 feet in length, on the tips of some of which were borne the seeds. The bulbous base undoubtedly was buried in the swampy mud for some distance, as the roots are not heavy and the tree otherwise would not have adequate support. The foliage of the trees was not heavy, much looser than in the tree ferns of to-day and the pinnules or leaflets were far apart (see pl. 2). There could have been no dense shade in this primitive forest; except, perhaps, for the heavy moist atmosphere sunlight could easily filter through. No higher forms of life existed there. The hum of insects was not heard, for there were no insects here at that time. All the sound one would hear, could one have been in that ancient forest, would be the murmuring of the winds in the tree tops or sounds from the neighboring sea or at times the howling of destructive storms. Three such forests, undaunted, reared themselves in all their glory, were cut down by the sea, buried, and fossilized.

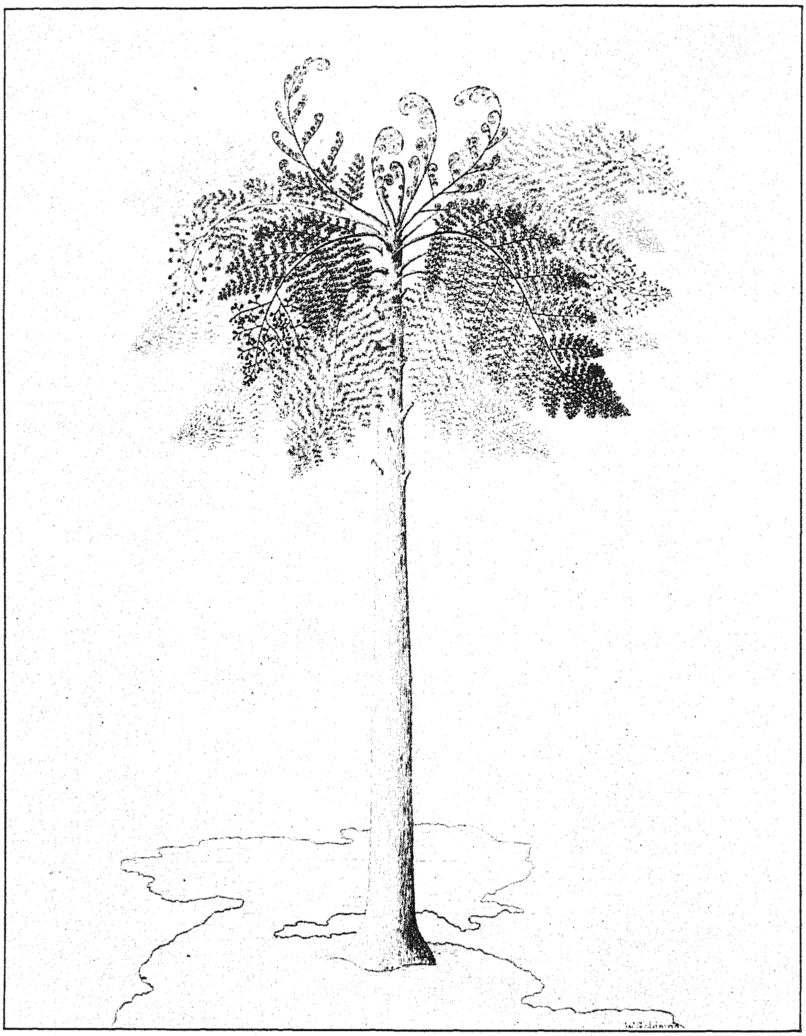
The restoration of the Fossil Forests of Gilboa (see pl. 1) was executed by the artist and sculptor, Mr. Henri Marchand, and his sons,

Paul and Georges, under the supervision of the writer. As shown in the accompanying photographic reproduction, it includes an idealized reproduction of the Gilboa area, showing the three forest levels, and here the actual fossil stumps are used. In the center foreground flows the Schoharie Creek, which is joined at the left in a series of falls by a tributary, such as the Manorkill. Looking across and beyond this fossil section one sees the painting of our vision of this ancient forest as it might have looked in the height of its glory. The lycopodlike trees (*Protolepidodendron*), which grew in small numbers in these forests, are also shown in the painting. At both sides of the painting are life-size restorations of the Gilboa tree, which merge imperceptibly into the painting. The artist has depicted so understandingly and skillfully the character of the forest with its heavy moist atmosphere that this restoration is at the same time both a scientific reproduction and a beautiful piece of art.



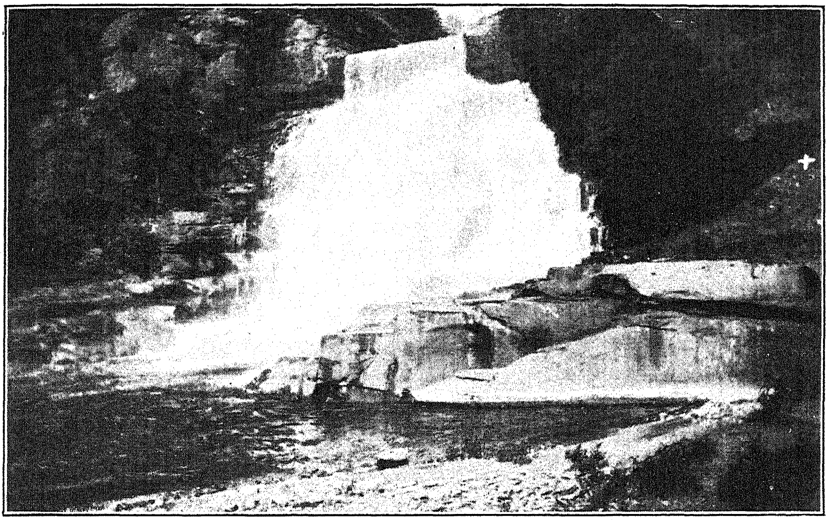
RESTORATION OF THE DEVONIAN FOSSIL FORESTS FOUND AT GILBOA, N. Y.

In the foreground is seen an idealized reproduction of the rock section at Gilboa, showing the three levels at which fossil stumps were found. The background is a painting of the forest as it probably looked when living, with life-size restorations at either side. This restoration is an exhibit in the New York State Museum, Hall of Fossil Plants. It was executed by the artist and sculptor, Mr. Henri Marchand, and his two sons, Georges and Paul, under the supervision of Miss Winifred



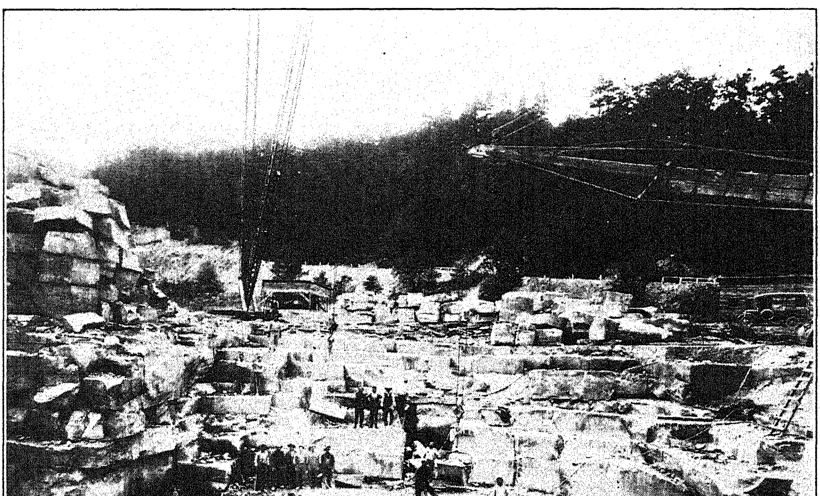
RESTORATION OF THE DEVONIAN SEED-FERN TREE

Showing the bulbous base, the gradually tapering trunk, and the crown of large fronds bearing at the tip, in some cases, the seeds and spore-bearing organs. (Restoration by Miss Winifred Goldring)



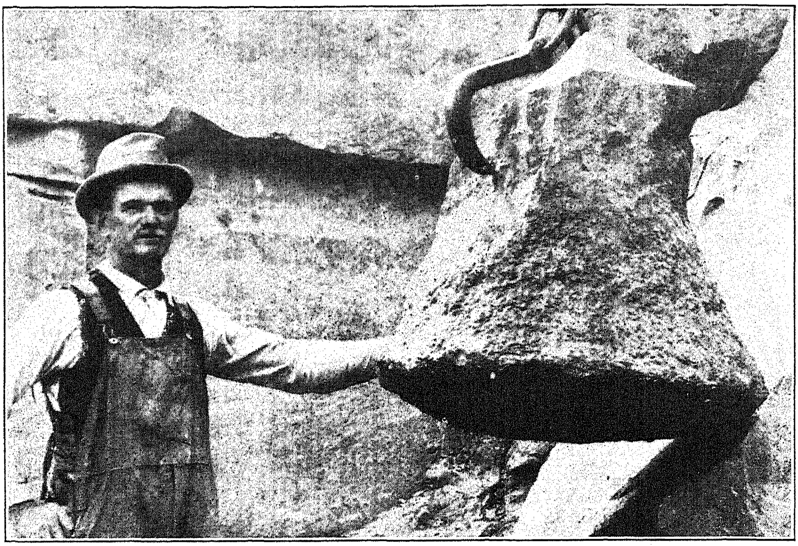
1. THE LOWEST FALLS OF THE MANORKILL, GILBOA, N. Y.

The horizon where the seeds and spore-bearing organs were found is at the level marked with a cross; the area worked extended some distance to the right



2. RIVERSIDE QUARRY, GILBOA, N. Y.

This quarry is located along the Schoharie Creek, one-half mile below the dam. From this quarry was taken the stone used in the dam and the greatest number, and the finest, of the fossil tree stumps. This constitutes the lowest tree horizon at 960 feet above tide

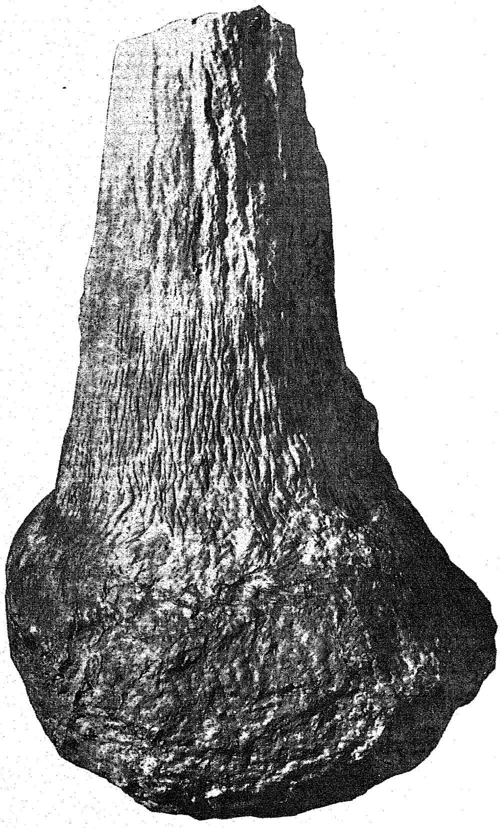


1. FOSSIL TREE STUMP IN RIVERSIDE QUARRY

Being removed from the spot where it had rested for millions of years

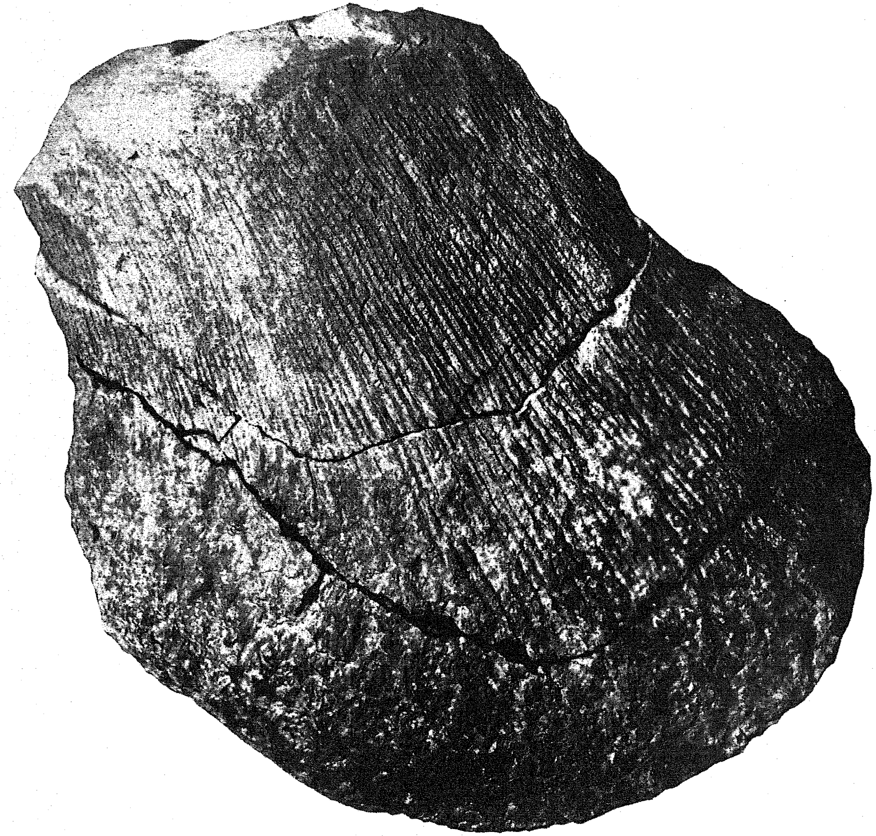
2. FOSSIL TREE STUMP

In place at the highest tree horizon at 1,120 feet above tide, along the road above the lowest falls of the Manorkill. The middle horizon (1,020 feet above tide) is at the site of the Gilboa Dam



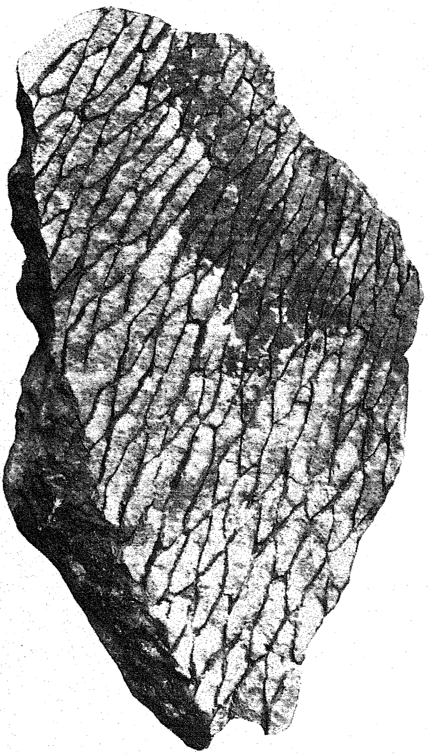
1. FOSSIL STUMP OF THE TEXTILIS TYPE

Showing rapid narrowing above the base and the network of interlacing strands of strengthening tissue. Height, 3 feet; circumference at base, 6 feet 3 inches (diameter, 23.8 inches)



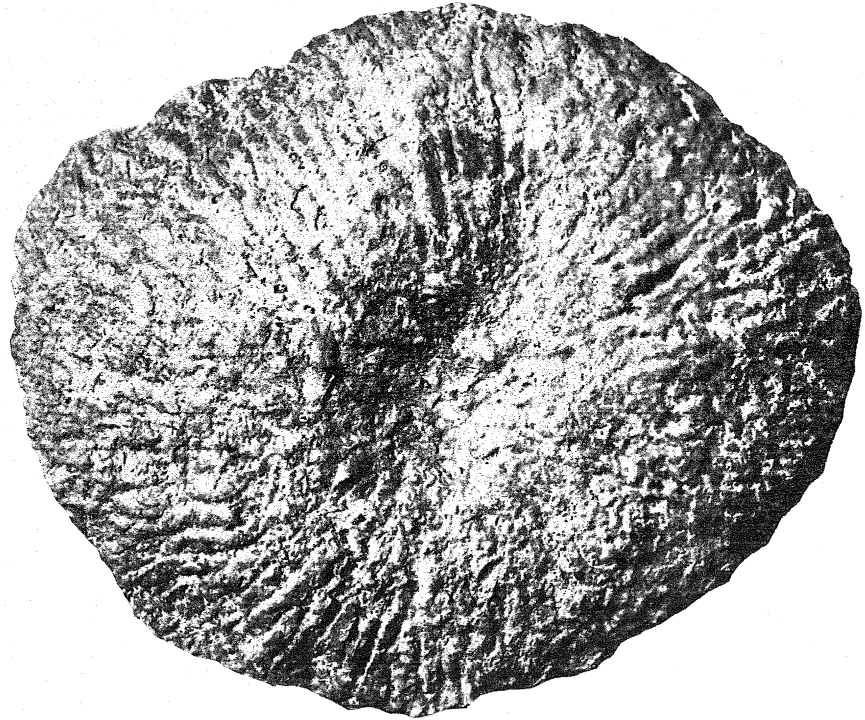
2. FOSSIL STUMP OF THE ERIANUS TYPE

Showing the more or less parallel strands of strengthening tissue. The stump narrows gradually above the base. Height, 38 inches; greatest diameter (left to right in figure), 38 inches; diameter at right angles to this, 30 inches



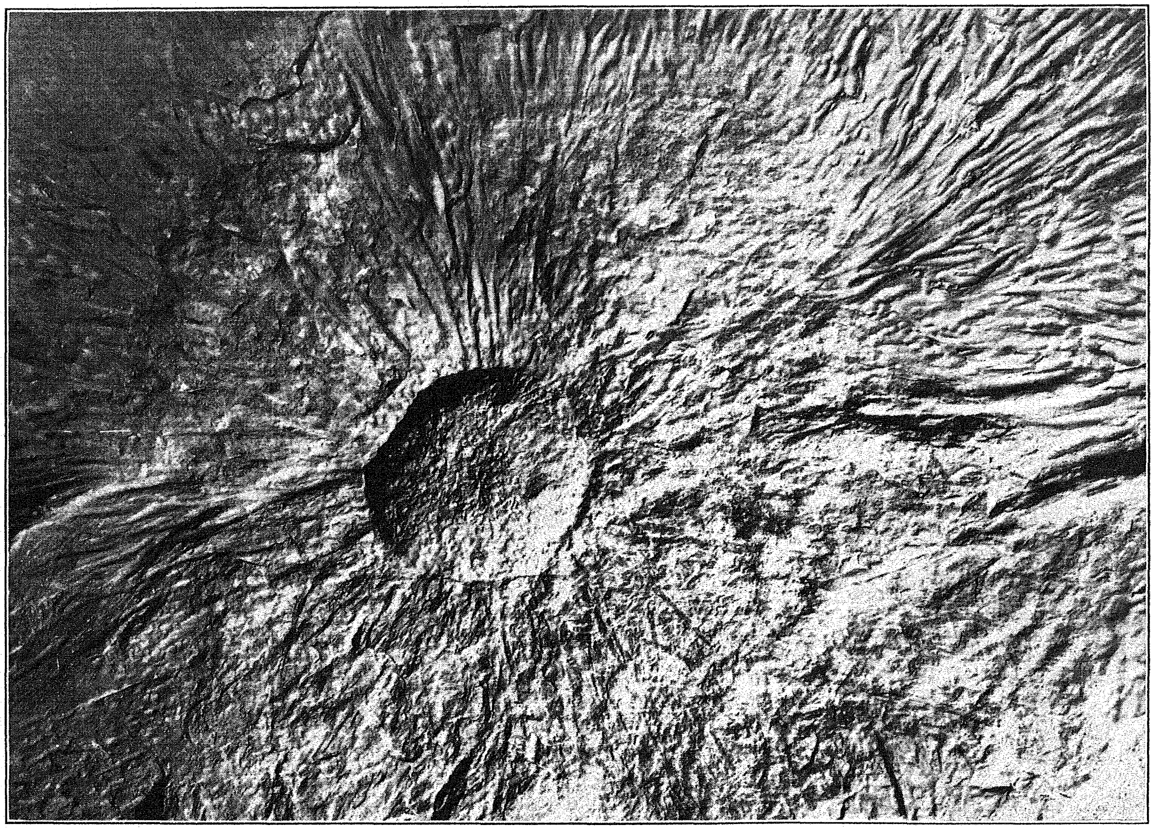
1. PORTION OF OUTER CORTEX OF ONE OF THE STUMPS

Showing the network of interlacing strands of strengthening tissue, of the textilis type of stump. Slab, about 15 inches long



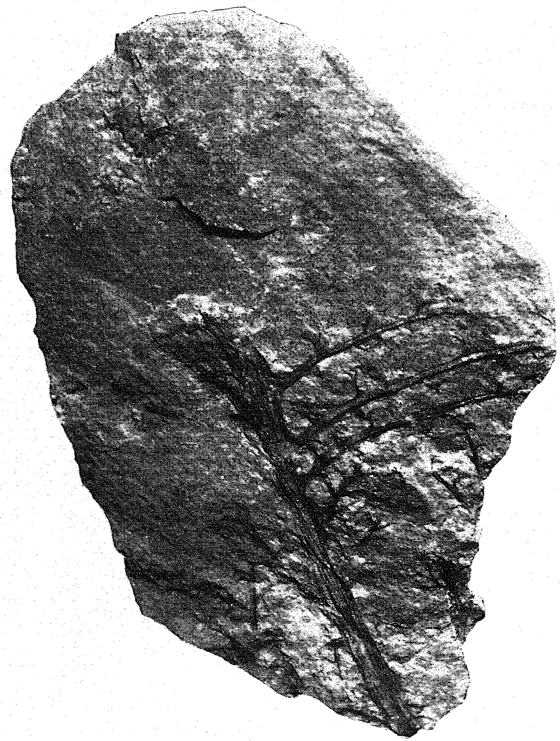
2. UNDERSIDE OF BASE OF STUMP OF TEXTILIS TYPE

Showing radiating ridges and furrows and the central depression. Diameter, 25 inches



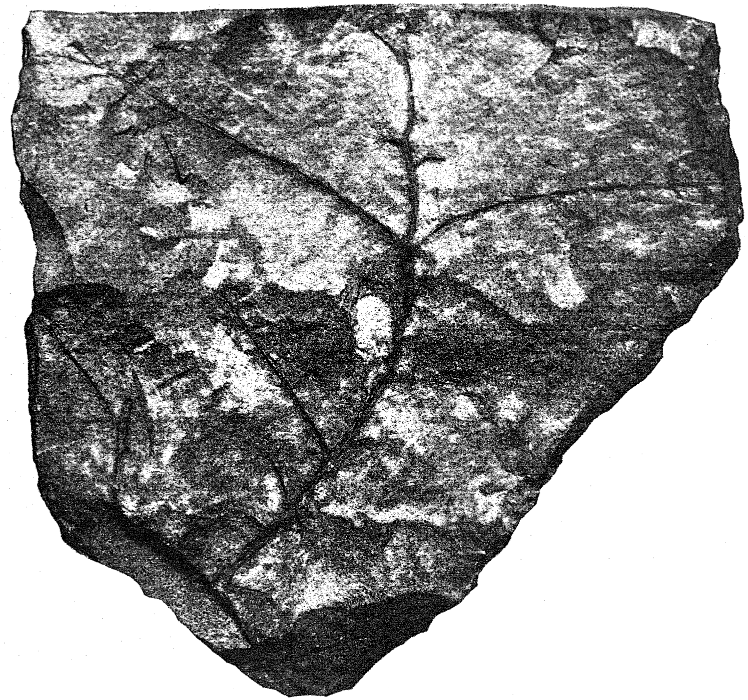
UNDERSIDE OF BASE OF SMALL STUMP

Showing the radiating straplike roots. Stump, 14 inches in diameter; slab, 6 feet 4 inches by 5 feet 7 inches



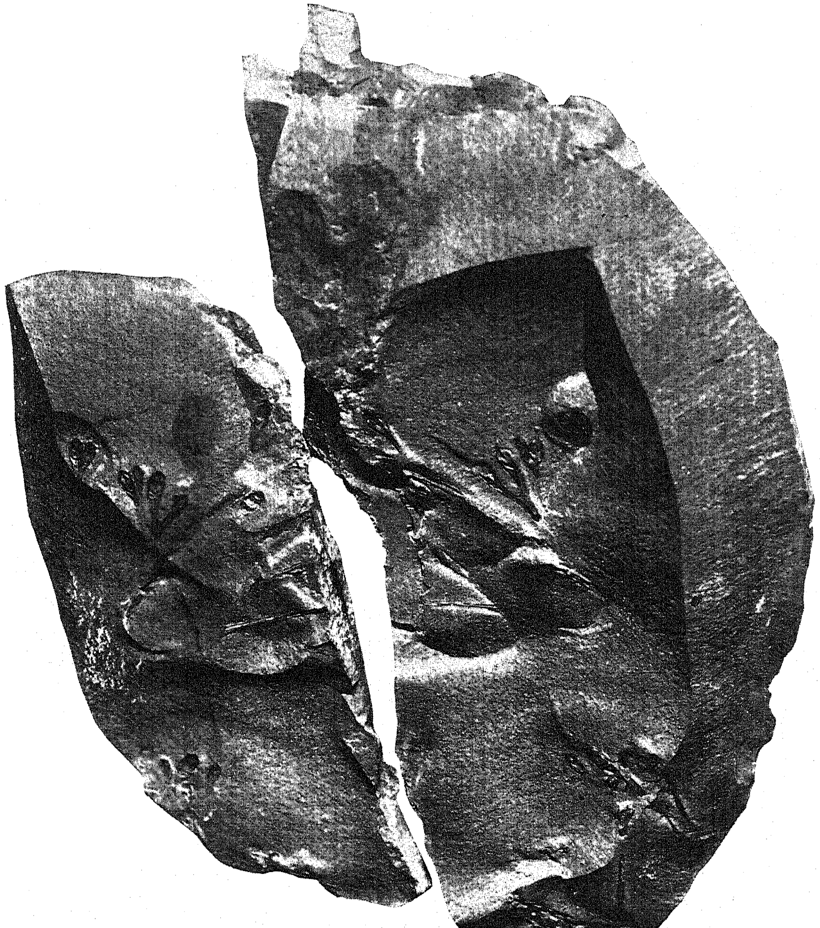
1. PORTION OF A FROND

Showing ultimate divisions with pinnules. The pinnules or leaflets are set rather far apart. They are bilobed with the lobes slightly recurved. Natural size



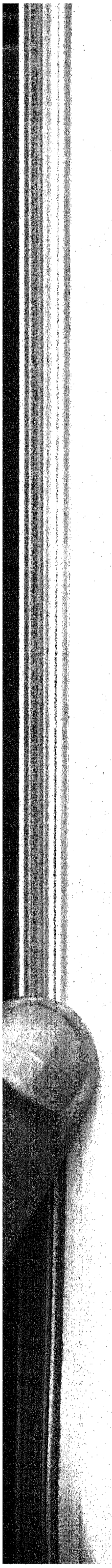
2. PART OF MAIN STEM, OR RACHIS, AND LATERAL BRANCHES OF FROND

The fronds had three divisions and must have been 6 to 9 feet in length. Greatest width of slab, 2 feet



SLAB SHOWING GROUPS OF SEEDS

The seeds were borne in pairs at the end of forked branchlets and were probably borne near the tip of the frond. Natural size



WATER DIVINING[1]

By J. W. Gregory, LL. D., D. Sc., F. R., S.
M. I. M. M. Glasgow University

I. MEDIEVAL AND MODERN USE

The existence of water, water, nearly everywhere, at slight depths underground, with often no clue where to find a drop to drink, is the basis of the widespread faith in the divining rod. Its value has been a subject of perennial controversy. Its use was denounced as idolatrous by the medieval church and forbidden by the Inquisition for the detection of crime. It has been repeatedly repudiated, after careful testing, by men of science and water-supply engineers. Though the church, academic science, and the practical man of affairs have alike condemned the divining rod, it has been commended by bishops and lesser clerics, men learned in higher physics have suggested that modern discoveries may explain its action, and it is employed by people whose judgment carries great weight. The rod has unquestionably been often successful, and it is perhaps more used now than at any previous time owing to the increased need for small shallow supplies of water. The enormous literature on the rod has been recently increased by an elaborate defense by Sir W. F. Barrett and T. Besterman (1926); wonderful powers are claimed for it in France in the works of M. Henri Mager (1913, 1920, etc.); a special journal and society have been founded in Germany for its study (Verband zur Klärung der Wünschelrutenfrage, i. e., the wishing rod problem); and last month it was the subject of an international congress at Hildesheim. Its use goes back to ancient times; it was doubtless the virgula divina of the ancients and is claimed as the rod of Moses that provided the Israelites with water in the desert.

Its modern use was apparently begun by German medieval miners in their search for metals. They had no reliable information as to the genesis and distribution of ore deposits, and in the absence of geological guidance a method which required the careful systematic

---

[1] Read at the session of the British Waterworks Association, Public Works, Roads, and Transport Congress, 1927. Here reprinted by permission of the British Waterworks Association.

traverse of the ground was as likely to be successful as any other. The use of the rod in medieval mining was described by many authors, and they often dismissed it as futile, as Agricola (1556) from mining practice and the Jesuit, A. Kircher (1678), after some experimental tests.

In the Middle Ages the rod was used for the detection of all sorts of materials—water, buried treasure, landmarks, metals, and murderers. For example, Aymar in 1692 by the rod traced some murderers from Lyons down the Rhone Valley until one of them was found at Beaucaire. The man was arrested, charged with the

FIGURE 1.—Divining for metallic veins in the sixteenth century

Preliminary operations of the miner. Two men have divining rods (A); one is cutting a rod, others are delving and discussing the plan of operation. From De Re Metallica of Agricola. Reproduced from Old Trades and New Knowledge (1926), by Sir William Bragg, K. B. E., D. Sc., F. R. S., director of the Royal Institution, by kind permission of G. Bell & Sons (Ltd.), the publishers

murder, and confessed. Aymar was employed in a later murder case; he was led blindfold over ground saturated with the blood of the victim; but the rod gave no indication, and he was ultimately found to be a fraud. His first success was probably due to his knowing who the murderers were and tracking them by ordinary means, as was suggested by Ozanam and Montuela (Recreations in Mathematics, Vol. IV, 1803, p. 263).

The use of the rod has been generally abandoned except for water, though it has been extensively employed in America in the search

for ores and oil. Some writers claim that it is effective for practically anything, and will find ores, oil, and buried treasure, and will answer questions on any problem. According to Mager, it will not only distinguish between different metals but it can be relied upon to indicate the percentage of different metals in an alloy. Sir Herbert Maxwell (1919, p. 174) describes how a blindfold diviner distinguished between different kinds of pottery. Sir William Barrett believed that it could read words in a closed envelope and could predict the results in a university examination (Barrett and Besterman, 1926, pp. 265 and 267). The divining rod is used by landowners and municipal authorities, and wells sunk at sites fixed by it have yielded useful supplies of water, where geologists and water-supply engineers have failed. The expense of using a water diviner was at one time disallowed by the board of trade, and members of county councils responsible for the expenditure had to pay it, but later decisions make the operations recommended by a diviner a legitimate charge upon the public rates. Firm faith in the divining rod has been expressed by bishops and members of Parliament, and in the recent work on the foundations of St. Paul's Cathedral the contractors used a diviner to determine the positions of water under the crypt. The claims for the success of water divining are innumerable; the practice is common throughout the civilized world, and its champions claim that its efficiency is established beyond reasonable doubt.[2]

II. THE ROD AND THE NATURE OF ITS MOVEMENTS

The rod usually employed is a forked twig of hazel with the forked ends each about 10 to 18 inches in length, about one-eighth to one quarter of an inch in thickness, and the butt a few inches long. It should be tough and springy, and therefore should be freshly cut. It is held with moderate firmness in the hand and often with each end of the fork passing between the little and third fingers (fig. 4), or between the second and third fingers (fig. 5). When thus held, pressure by the finger above the rod bends or twists it and causes the end to rise or fall. In the first mode of handling the pressure of the third finger may be sufficient to break the rod and bruise the little finger.

The rod is carried in various ways. The French diviner Bléton, who made a great sensation in the latter part of the eighteenth century, placed a curved rod on his open hands, and it rotated over underground water (fig. 2); but when this rotation was shown to be due to a slight movement of the muscles of the hand, it was dismissed as

[2] Some recent correspondence from the Observer, Muncipal Engineering, and The Surveyor has been reprinted in the British Waterworks Association official circular, 9th Ser., vol. 9, June, 1927, pp. 413–417. I am much indebted to Mr. G. P. Warner Terry for a long series of press references to the subject.

a conjuror's trick. Mager rejects Bléton as a charlatan who used the rod to amuse his spectators.

Whatever may be the ultimate cause of the movement of the rod the immediate cause is almost universally recognized as some conscious or subconscious movement of the diviner's hands. The movements may be divided into three classes: (1) Those based upon fraud and practical jokes; (2) those due to unconscious imposture, as with people who believe that they are endowed with some special gift wherein they are superior to their fellows, and the claim for the power of water divining is often associated with personal egotism;

FIGURE 2.—The Bléton method

FIGURE 3.—Charles Adams of Rowberrow

(3) after these categories are separated, there remains so large a residue for which some other explanation is necessary that the conclusion has been adopted that there must be some external physical force which directly or indirectly causes the movement of the rod. I was at one time inclined to share this view. A friend in whose practical insight I had full faith told me of the success of water divining on his station in western Victoria. I had previously heard the evidence of some Australian cases, without being impressed by it; but in this instance there seemed more reason to suspect some special power. The diviner said the gift was hereditary, that he could not recognize water in an iron pipe, that the rod never answered on a wet day, or

even in a cold moist wind, and that he could not detect an open sheet of water. The rod was affected by water that was buried underground, but not by water at the surface.

These statements suggested that the man might have some idiosyncracy by which he was affected by slight sharply contrasted differences of moisture in the atmosphere. Hence walking across a sheet of basalt he might feel moisture rising along cracks, as it would be sharply separated from the drier air on either side, while he would not recognize surface water because the increase in humidity around it would be gradual. It seemed possible that by the hands being held in a constrained position the muscles, to use the common phrase, may go to sleep, and then be contracted by a slight stimulus to the nerves of the skin. The sensitiveness of the rod has been compared to the power of some animals to scent distant water; but the two processes must be different or the diviner would recognize surface water.

The notion that the movement of the rod may be due to variations in the water vapor appears, however, untenable, because it would not

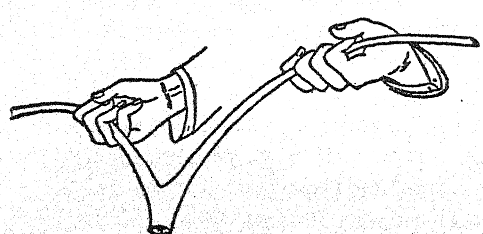


FIGURE 4.—A common method of holding (after M. Culpin)

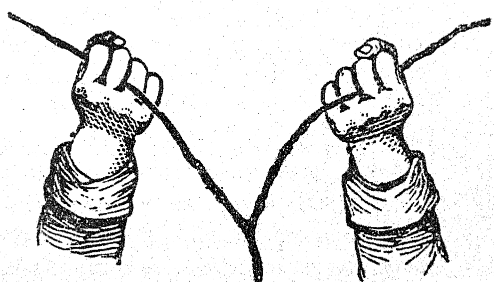


FIGURE 5.—The rod as held by Mullins

explain its response to metals, murderers, and ordinary citizens, or its unfailing taste as a connoisseur of pottery. It would not also explain its action on wet days, and one of the tests by M. Mager (1920, p. 23) was during heavy rain; and it is dismissed as utterly improbable by three eminent physiologists, whom I have consulted on the matter.

There are three rival lines of explanation. The first, that the rod responds directly to some external physical influence, has been encouraged by the discovery of radioactivity. This type of influence has been described as rhabdoactive by Prof. P. Lemoine (1913, p. 42), as rhabdomotoric by von Uslar (1912), or as the activité universelle by Henri Mager, who is the chief champion of the response of the rod to an external physical force. He claims that all bodies emit lines of force, which are essentially of the same nature as electric and magnetic waves, and that they may be recognized by various physical instruments such as the divining rod, and some forms of pendulum. He claims that when an expert carrying the rod crosses these lines

of force the waves pass through his body and thus cause the movement of the rod. Various instruments such as the Mansfield water finder also rely on the existence of some physical force. As lines of force are out of my province I have referred Mager's last book to Professor Desch who kindly reports as follows:

I have read "Les Baguettes" with care and with increasing bewilderment. The author appears to be honest, and gives a detailed account of a very large number of experiments, and yet the results are evidently worthless, and utterly inconsistent. Sometimes he can make great alterations in the conditions, and sometimes the slightest change alters the whole effect. Sometimes he professes quantitative accuracy, and then it becomes clear that any foreign matter in the neighborhood would destroy the effect. He gives details of the analysis of complex substances without explaining why the effect of one constituent does not mask that of another. I do not think that this book can be accepted as furnishing any support for the view that the diviners have powers of detecting water or minerals. The author's lines of force which build themselves up into a kind of wall are utterly inconsistent with the known properties of lines of electric or magnetic force.

According to Mager (1920, p. 12), the movement of the rod can only be interpreted after prolonged training, and its successful use requires 10 years of constant laborious systematic experience. The ordinary diviner he distrusts as somewhat of a quack, because of the lack of training, and he regards the English diviners as less efficient that the French (Mager, 1913, p. 121).

A physical cause for the movement of the rod is not to be dismissed as impossible, but so widespread and powerful a force should be easily demonstrated. The discovery of radioactivity was at once followed by convincing experiments which proved its existence. If the lines of force of M. Mager exist they should be demonstrable by consistent experimental results; but the statements regarding them are vague, indefinite, and unconvincing.

Mager and his work are summarily dismissed by the United States Geological Survey, for A. J. Ellis (Water Supply Paper 416, 1917, p. 23) states: "In all its weird history no more extravagant and absurd claims were ever made for the divining rod than those which are maintained at the present time by Henri Mager."

The alternative explanation is that the movement of the rod is due, though perhaps unconsciously, to the diviner. Barrett and Besterman dismiss the evidence for an external physical force by arguments which seem unanswerable. The view that the action on the rod is psychic and not physical is supported by the fact that any sort of rod will serve. In the early days it had to be a twig cut about sunset or sunrise by a man standing in a particular position, and with the sunlight shining through the fork of the twig, and it would respond only on certain days. But now any twig serves, and on the treeless plains of Australia a piece of iron wire taken from the nearest fence will act as well; or it may be of aluminium, or a piece of clock spring, while

some diviners, such as Gataker, used their hands alone. That the twig is moved by some impulse from the diviner is rendered probable by the way in which the rod is generally held, for as previously explained, a slight movement of the finger causes a marked movement of the rod. The movement by the diviner is explained in two ways. The theory adopted by Barrett and Besterman attributes the movement to "cryptesthesia"—a kind of second-sight, by which the diviner becomes conscious of the presence of any object for which he is searching, such as oil, metals, buried treasure, letters in an envelope, future events, underground water, or some special person. The evidence for this form of second-sight is similar to that for the ordinary kind claimed by spiritualists.

The alternative view is that the diviner unconsciously or subconsciously moves the rod owing to an impulse due to unintentional suggestion from the bystanders or by his recognition of indications favorable for water. If the diviner is accompanied by people who know where there is a hidden spring, or where some material lies buried, or which envelope contains the test metal, they unconsciously give away the secret, as in ordinary thought reading; but this explanation does not answer for cases of water divining in which the bystanders are trusting to the diviner for guidance and have no preconceived ideas.

This unconscious movement of the rod by the dowser is explained by Dr. Millais Culpin (1920, pp. 24–33 and 34–43) as an instance of dissociation of the various streams of activity which flow side by side in the human brain. Many actions are unconscious as by frequent repetition they have become automatic, and some are now purely instinctive. Doctor Culpin instances the motor driving of an expert whose car slips through crowded traffic while he converses on some abstruse problem. A young pupil reads letter by letter, while a quick reader takes in sentences at a time and is unconscious of the individual letters. Similarly many streams of nervous activity are dissociated from the conscious movements. Hence a man going over a tract of ground may notice signs of water unconsciously, and some slight mental action may cause the twitching of a finger and a jerk of the rod. While some dowsers may be deliberate frauds, and others may be duped by their vanity, many of the best dowsers probably act by their dissociated mental activities.

A man like Mullins may by long experience or special quickness of observation instinctively recognize where water is likely to occur, and by some subconscious motion of the hand cause the warning movement in the rod.

Dr. H. Haenel, after a careful investigation of the physiological action of the divining rod, concludes that the nerve system is the receiver, carrier, and transmitter of the whole divining rod phenomenon. (Schr. Verb. Klär. Wünschlr., pt. 8, 1918, p. 28.)

III. THE EVIDENCE FOR DIVINING

The decision between these conflicting explanations must depend on the evidence. It is overwhelming in quantity, and though I have dipped into it for years I have not read a hundredth part of it. Fortunately, however, the best evidence has been collected and summarized by advocates of water divining. Barrett and Besterman's Divining Rod, and the series of works by Mager state the case for the action of the divining rod by psychic and physical causes, respectively.

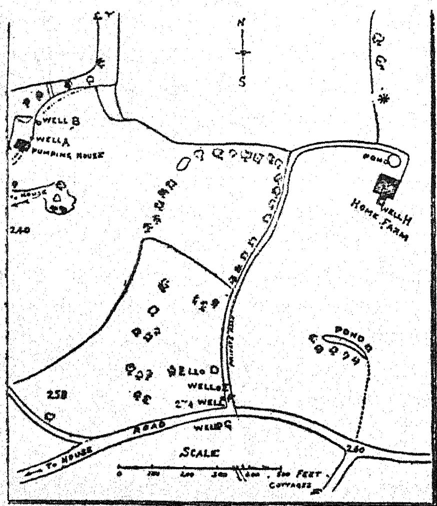


FIG. 15. WARNHAM LODGE PARK
After the 25-in. Ordnance Survey Map: Sussex (II. 15)

FIGURE 6.—Barrett & Besterman's Figure 15

Barrett and Besterman (1926, Chap. IV, pp. 65–102) put forward three cases as of especial weight—those at Horsham, Waterford, and Carrigoona. Near Horsham in northwest Sussex Mullins found water for Sir Henry Harben at Warnham Lodge. The country consists of a sheet of Weald Clay with, to the southeast of the house, a low hill capped by a bed of sandstone. Around the top of this hill (fig. 6) five wells were sunk at sites selected by Mullins; water was found in two cases at the depth of 12 feet, in one at 19 feet, in another at 35 feet, and in the well C, apparently a misprint for G, at a depth unstated. Mullins' selection of these sites and his success do not appear surprising. Many hills in the clay districts of the southeast of England are capped by sand, gravel, or sandstone, which protects the clay from being worn away by wind and rain. In many cases the only chance for shallow wells is upon such hills, for their porous beds are charged with rain water which is discharged by springs or wells. The occurrence of water on the hill at Warnham would appear probable to one experienced in well sinking in such positions, for the

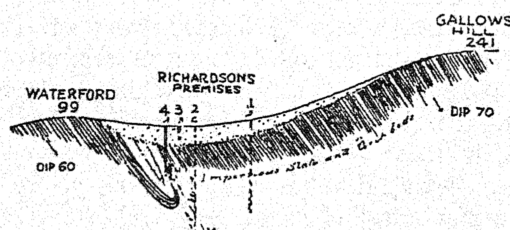


FIG 10 THE WATERFORD EXPERIMENT

FIGURE 7.—Barrett & Besterman's Figure 19

natural explanation of the curved pond on the northeastern slope of the hill would be that it is fed by percolation from a water-bearing bed on the hilltop.

The second case, which Barrett and Besterman describe as "one of the strongest we possess," was at Waterford. A series of wells had been sunk into steeply tilted beds of slate and grit, but without full success. Mullins recommended a line shown in the section (fig. 7) nearer the eastern (99 ft.) outcrop of the slates. Water running down from Gallows Hill would collect in the drifts and drain northward to the River Suir at right angles to the section. The deepest part of the drift-filled valley crossed by this section would be normally, owing to the slope of the land and the dip of the slate, near the 99-foot outcrop. Water would collect in this depression and soak into any porous rock beneath. The well, according to the section, entered a trough-shaped infold of grit which would serve as a reservoir for water that percolated from the overlying drift. It yielded an average of 1,560 gallons per hour (later reported to yield 2,000 gallons), whereas the next well (B) yielded only 230 gallons an hour, which, being inadequate, was regarded as a failure. The three wells put down before Mullins' trials passed through slate and the upper parts of the beds of grit, in which there would be nothing to hold the water. Mullins' line lay along the most likely position in which to get water from the overlying drifts, as from them it could soak into the underlying rocks. Mullins had this clue, and had the good luck to strike the infold of grit which gave the large supply.[3]

The third case is that at Carrigoona to the south of Dublin. The diviner was William Stone, and the test was under the direct supervision of Sir William Barrett. Barrett and Besterman put it forward as conclusive proof of the reality of dowsing. William Stone, after going over the ground, said that plenty of water would be found anywhere along a marked line (which is presumably the line 1—3 in Figure 8, though it is stated in the text to be the dotted line on their Figure 20 which is not reproduced, and for which the statement would appear improbable). Good water was found as Stone had predicted, at his sites 1 and 3, and very little at bore 2. Sir William Barrett was emphatic that Stone paid little attention to the surface features; but the line he chose was that which I think any person experienced in finding water would have selected from obvious surface indications. The adjacent bed rock (quartzite) is marked on the map as outcropping on both the eastern and western sides of the field, which lies on a drift-filled valley. The position No. 2 would be obviously unfavorable as it is only 10

[3] Professor Sollas tells me that the success in this case was shown to be pure luck by the failures by which this dowser distinguished himself shortly afterwards.

yards from the outcrop of the rock (Barrett and Besterman, fig. 28, p. 95), so the drifts would be shallower than under the center, and water flowing over the bed rock from the side would pass under No. 2, and collect along the deeper line past the bores 1 and 3. The position of the favorable line is fixed within comparatively narrow limits by the fact that the rock is also marked as visible at the southeastern corner of the field; the drainage from this patch of drift to "the rocky valley" shown to the south must go under the ground marked as "common" between the two exposures of rock. As Stone walked over this ground he doubtless saw the rock outcrops and the limits of the area of sand and gravel, which alone would yield shallow supplies of water. A man experienced

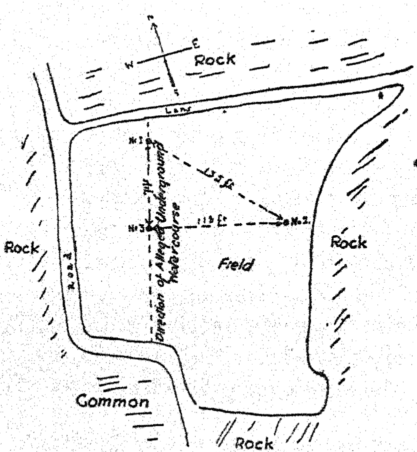


FIG. 21. THE CARRIGOONA EXPERIMENT

FIGURE 8.—Barrett & Besterman's Figure 21

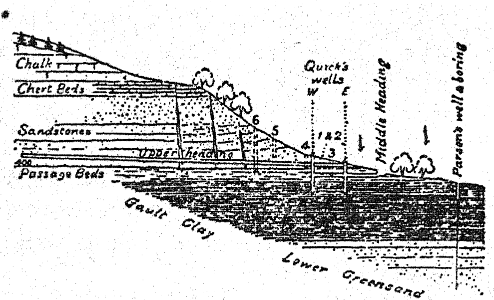


FIG 49 THE SHANKLIN EXPERIMENT: SECTION

FIGURE 9.—Greatwood Copse, Isle of Wight. Figure 49 of Barrett & Besterman

in the search for water would have known that the line through 1 and 3 would have been the most promising, even if he had not a mental vision of the water flowing off the bedrock and collecting in the sand in the lower part of the drift-filled gulley.

Another case quoted by Barrett and Besterman (1926, p. 208) as "one of the best on record," was near Greatwood Copse at Shanklin in the Isle of Wight. (Fig. 9.) The permeable Upper Greensand there rests upon an impermeable clay, the Gault. The sandy beds immediately above the Gault are naturally water-bearing. A double well yielded about 4,000 gallons a day, and more was wanted. A heading was then made through the sandstones on the advice of H. Bristow of the Geological Survey, and it obtained from 9,000 to 18,000 gallons a day. Three other geologists, Topley, Norman, and Sir Aubrey Strahan were subsequently consulted, but their proposals were not carried out; and Topley pointed out that the heading driven in accordance with Bristow's advice was at too high a level. Mullins

was engaged in 1893; the sites he recommended were not tried, but a well sunk as near them as was practicable yielded no water. Subsequently two members of the local board tried dowsing, and seven wells were sunk where they recommended in the lower part of the sands, and into or near the top of the clay. One well yielded up to 7,000 and another up to 12,000 gallons a day, the total yield of their seven wells varied from 1,250 to 24,000 gallons a day, whereas the original double well and the Bristow's heading yielded from 9,000 to 24,000 gallons a day. Nevertheless, this case is claimed as a great triumph for the dowsers as against the geologists; but the facts are that though four geologists reported, the proposals made by three of them were never tried, and though the heading made at the suggestion of the fourth was at too high a level, it was the most productive work of the whole series. The dowsers' wells were put down through the Greensand to the water-bearing layer at the top of the clay, and obtained their supplies from the level previously proved to be water-bearing by the engineer who made the first two wells.

The happy selection of the sites in these four cases was in accordance with common sense and did not require cryptesthesia.

Henri Mager in his book (1920, pp. 16–26) describes the test in the Bois de Vincenne's near Paris in 1913, which he claims as convincing. Thirty diviners came, but only four agreed to take part in the trials. The first test was to map an underground quarry. One diviner marked its borders with approximate accuracy; a second was not very successful because, according to Mager, he held his rod by a glass phial; the third claimed to have found the pillars which supported the roof in the quarry, but there is no evidence as to his accuracy; and the fourth reported coal. The next test was to find a buried mass of copper and a cast-iron grille. The copper was not found because, according to Mager, it was neutralized by a metallic peg above it, but the two diviners identified the position of the grille. Several diviners were then tested for water in torrents of rain, but no definite information as to the results is given, though Mager claims that they were concordant. Finally, two of the diviners were tested with envelopes containing different metals, and both of them found one containing copper. These results seem to me by no means convincing as the success in some cases was only partial and in others the information given is too indefinite for an opinion.

IV. INDEPENDENT TESTS OF DIVINING

Many tests of divining have been made both by geological surveys and individuals. The Government geologist of South Australia, Dr. Keith Ward, reports (November 5, 1914) that in that State an area had been tested and water found alike where, according to the divining rod, there was none, and where it gave indications of water. In

New South Wales the results of an extensive test were also unfavorable to divining; the commission for water conservation and irrigation reported (June 10, 1920) observations on 142 bores; of 56 bores located by the divining rod 70 per cent were successful, but of the 96 bores sunk without it 87 per cent were successful; and as these tests were regarded as utterly discrediting the use of the rod the tests were stopped. Prof. Griffith Taylor, of Sydney (Proc. R. Soc. Vict., n. s., xxxiii, 1921, pp. 79–86), reports two cases that he carefully investigated near the Australian capital, Canberra. In one case a flowing stream was predicted; the stream was not there, but a well reached the watertable, and thus obtained water. In the other case the divining was a complete failure, and Professor Taylor adds (Ibid., p. 83) that few people know of that case.

In England the most systematic test was that organized at Guildford by the Sanitary Record and Municipal Engineering. (Vol. LI, 1913, Jan.–June, pp. 355–358, 391–392, 462–466.) The tests were supervised by a number of authorities on water supply with the late William Whitaker as chairman. Many diviners attended; seven of them were selected, and were conducted separately over a route of which the water conditions were known to the committee. The indications of each diviner were marked on separate maps, which are published in the official report. They tested three sites. At the first, shallow gravel lay on London Clay; the gravel held water at the depth of 20 feet on the southern side, but none at the swampy northeastern part of the field. Water could be found in the Chalk at the depth of 150 feet equally well under all parts of the field. The diversity of indications by the diviners was very marked (fig. 10); one found a small stream across the northern part of the field, and a broader stream a little farther south. Others found springs irregularly scattered over the field. Some of the indications were quite isolated, though with so large a number on the small field naturally there were some coincidences.

Site No. 2 was a reservoir covered by a lawn. On part of the lawn there was an iron pipe which all the diviners saw, and reported water beside it, though the ground there was dry. In the distribution of the water the diviners were utterly at variance, although most of them were sure that there was none in the middle. (Fig. 11.) One found water at the north angle; another found water at two places; a third found it at three places on the margin; a fourth at two places on the margin; a fifth found two streams; and a sixth, one stream about equidistant between the two.

Site No. 3 was a field on Chalk with water under all parts of the field; a spring had been found on the eastern boundary some years before, and a sewer with running water crosses the field. (Fig. 12.)

In this case the diviners agreed better amongst themselves, though not with the facts. Four of the diviners inferred a stream of water under the eastern part of the field, but they did not agree as to its position; the western half of the field was left as practically barren;

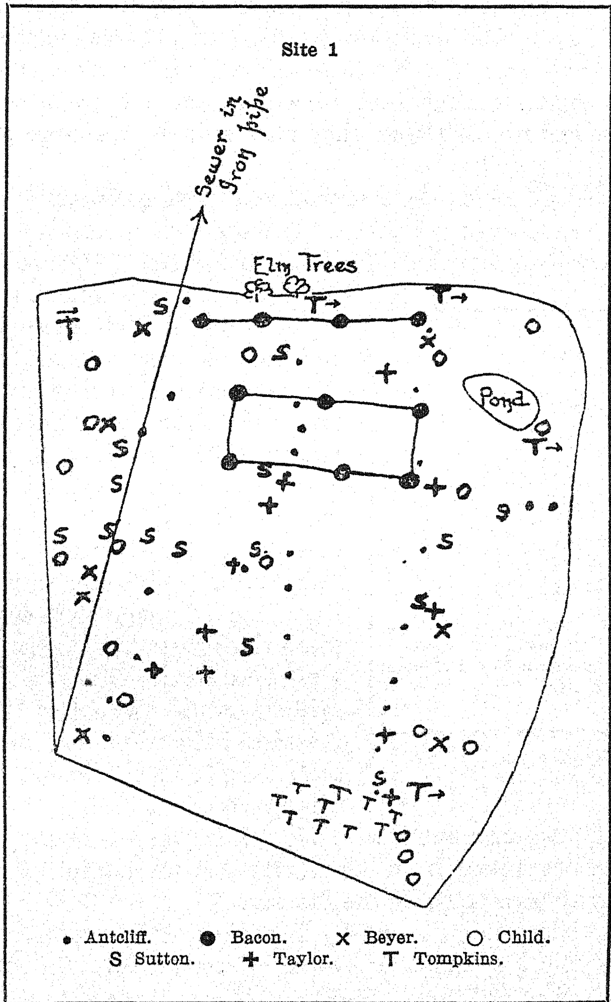


FIGURE 10.—The Guildford test, April, 1913. The lines connecting some bores were represented as streams

nothing was found over most of the sewer; one diviner detected water near the hidden spring, but others found nothing near it.

After lunch four of the diviners tried finding coins under a carpet, but without success.

The committee in their report on the experiment state (ibid., p. 466) "on comparing the state of facts known to exist with the indications given by the diviners, that whatever sensitiveness to underground waters may exist in certain persons, of which some evidence has been given, it is not sufficiently definite and trustworthy to be of much practical value. Moreover the lack of agreement with each other shows that it is more a matter of personal mentality than any direct influence of the water. The diviners, as a rule, confine their attention to small streams of water, and as there are few places where these can not be found, they may well show a large percentage of success."

Prof. J. Wertheimer, dean of the faculty of engineering of Bristol University, conducted a series of experiments to test various powers claimed by diviners. (Journ. Soc. Arts, 1911, vol. 59, pp. 384–391.) For example in the kitchen at Brislington Hall there is a well, and three dowsers were asked to locate it; they reported water in many places under the floor (fig. 13), but not the known well. One of them having determined three positions all away from the well (C1, C2, C3), on Figure 13, when told where it was, said he could trace a course of water to it from his C1. One of them claimed to know when the water was flowing through a pipe, and when it was stopped, and said he would pay £5 to the Bristol Hospital if he were unsuccessful. He paid the £5. Experiments were also conducted for finding coins under saucers and cushions, but with more failure than success. Professor Wertheimer concluded from the results that the motion of the rod is not due to any cause outside the dowser.

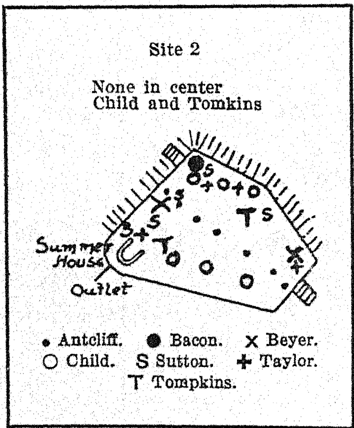


FIGURE 11.—The Guilford test, April, 1913

Among other tests was one by Professor Sollas at the request of the Society for Psychical Research (Proc. Bristol. Nat. Hist. Soc. N. S., Vol. IV, 1885, pp. 116–125). The dowser, Thomas Young, selected two points in a field at one of which he said there was water, and at the other none. Sollas predicted that as regards water, both sites would be found alike, and he claimed in his report that equal quantities of water were found in both. His conclusion has been criticized (Barrett and Besterman, p. 59) on the ground that a subsequent visitor represented one well as 10 feet deep and the other 24 feet. According to Sollas one well was 29 feet deep, and the

other 17½ feet. The essential point of this test, however, was that water was found where the dowser said there was none.[4]

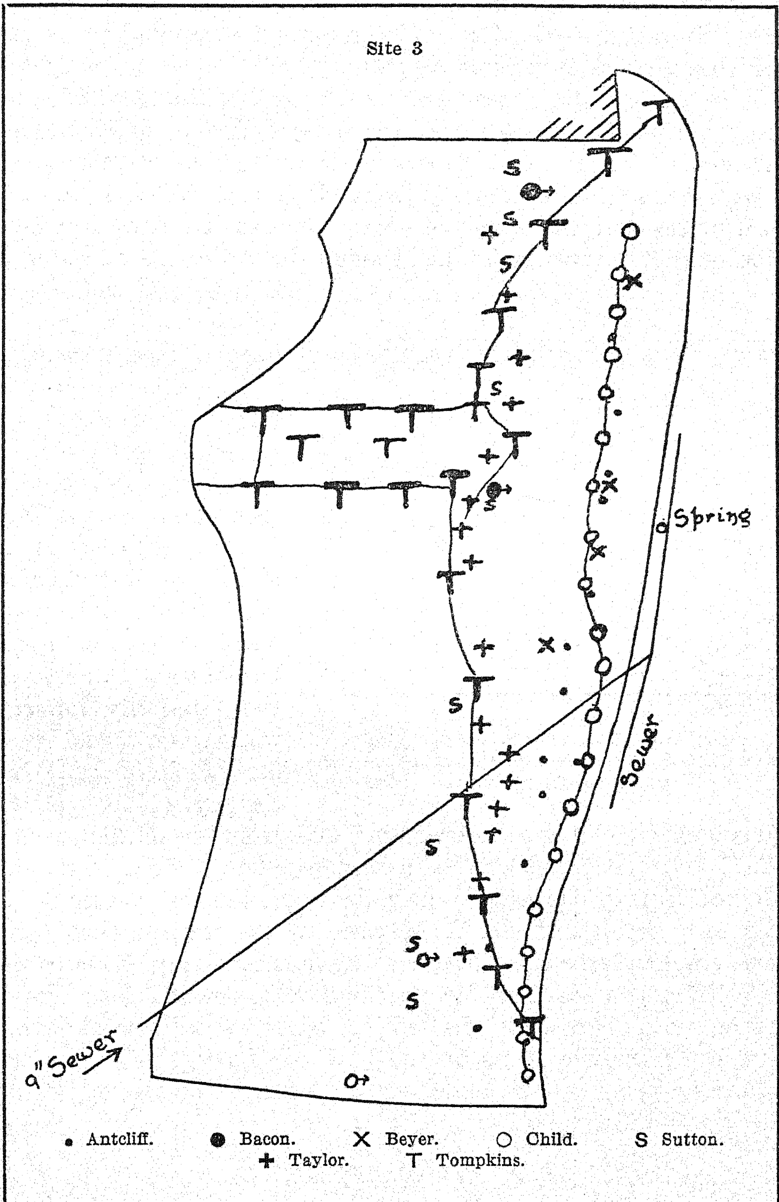


FIGURE 12.—The Guildford test, April, 1913. Lines connecting some bores were represented as streams

[4] Professor Sollas tells me that in regard to the site which the dowser predicted would be dry "there was never any question of more or less water; it was water or no water." In both wells the water stood at the same level. In reference to the unequal depth of the two wells Professor Sollas tells me that while pumping out one in order to measure the rate of flow the sides caved in and it was abandoned.

In an extensive test in Southwest Africa, of 800 places indicated by the rod 148 were bored; 21 per cent yielded no water, but in the rest some water was found, and in 90 per cent of them at the depth predicted. In a test at the Paris Waterworks the results were such as would have come from mere chance.

The divining rod has been frequently used in Essex. The success of the well sunk in 1894 on the recommendation of William Stone at Thremhall Priory near Bishops Stortford has been often quoted; but we owe to G. S. Pritchett (Essex Naturalist, VIII, 1894, p. 50) record of the fact that two wells were then sunk on the recommendation of Stone, and that at one, though the indication of water was so powerful that his rod split, a well dug 55 feet deep yielded no water.

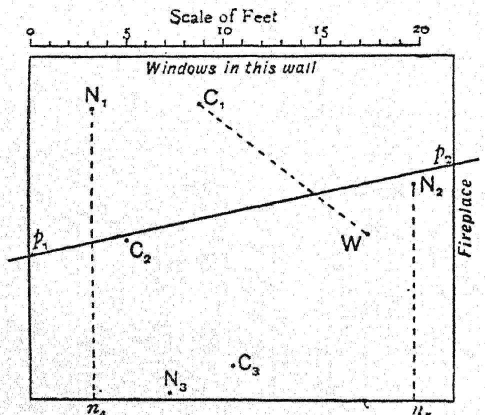


FIGURE 13.—Kitchen of Brislington Hall
W, Well; C 1–3; P 1–2; N 1–5; sites and lines indicated by three diviners

The experts on water supply connected with national geological surveys have often reported on divining, and so far as I know they are unanimously against it. H. B. Woodward, who was a member of the British Geological Survey and was especially connected with water problems, in his Geology of Water Supply (1910, pp. 239–242), refers to divining as "uncertain," and often "remarkably unsuccessful," and quotes authorities in support of that view. The U. S. Geological Survey has issued a memoir on the subject (Water Supply Paper 416, 1917), and O. E. Meinzer in the introduction (p. 5) asserts emphatically its "practical uselessness," and declares that "it is difficult to see how for practical purposes the entire matter could be more thoroughly discredited, and it should be obvious to everyone that further tests by the U. S. Geological Survey of this so-called 'witching' for water, oil, or other minerals would be a misuse of public funds."

V. AN OIL DIVINING TEST

The rod has been largely used for oil finding or "oil-smelling" in America. A careful test of its powers in this respect was made by Sir John Cadman at the research station of the Anglo-Persian Oil Co. at Sudbury. Sir John Cadman tells me that the people engaged in burying the oil were removed from the vicinity during

the test, and no one present at the trial knew where the oil was placed. Sir John Cadman regards the result as a "complete fiasco" as "in no case were the diviners able to show any justification for their contention that they could discover such deposits." The following memorandum, sent me by Sir John Cadman, describes this instructive experiment.

As a result of a request received in April, 1925, from two "Professional Water Diviners" who hoped to be able to ascertain:

"AREA OF THE OIL POOL

"*Depth.*—(Great accuracy in depth has been obtained in divining for water, and it is hoped to apply the knowledge so obtained to oil.) It has not been possible to test this thoroughly but we feel confident that this presents no insurmountable difficulties.

"*Position.*—We hope to be able to indicate the spots where the oil supply is heaviest.

"*Quantity and quality.*—Experiments up to date have shown a markedly different reaction to varying quantities of oil. Experiments with fats prove that the spirit is the essential factor influencing the rod."

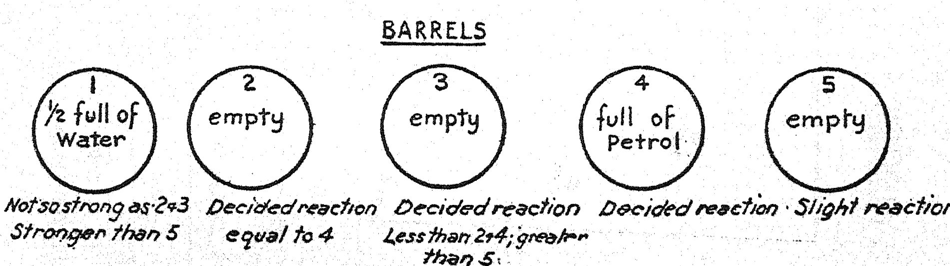


FIGURE 14.—Meadhurst oil experiments. Diviners' reports on lower lines

I authorized the carrying out of a somewhat exhaustive test at our experimental station at Meadhurst, Sudbury-on-Thames, with the following result:

They having claimed to be able to detect hidden deposits of oil and to give an indication of its amount and of the richness of its petrol content, I had two series of tests prepared.

For one (fig. 14) a series of five steel 50-gallon drums were set out. One of these contained water, one petrol, and three were empty.

For the other test (fig. 15) eight deposits were buried about 12 inches deep in the paddock. Three of these deposits were oil contained in tins (4 gallons crude, 4 gallons petrol, and 1 gallon petrol, respectively). These quantities were chosen (as in the "barrel" series) to test the claims that the location, quantity, and petrol content of deposits could be detected. In order to parry the possibility of an objection that a metal container might neutralize their efforts two further deposits (gas oil and crude oil) were laid down without any container. Finally, to obviate any betrayal of the locality by traces of surface disturbance three other deposits of tins containing no oil were laid down and special care was taken to render the surface identical in appearance with the surrounding ground.

The séance was attended by a personal representative, the chief chemist, and two geologists, the areas submitted for test being the sports field, the paddock, and the grounds of Meadhurst.

In the sports field (where no oil had been placed) eight definite locations were detected.

In the drive at Meadhurst (where again no oil had been put) a very strong location was reported—the strongest they detected during the whole of the test.

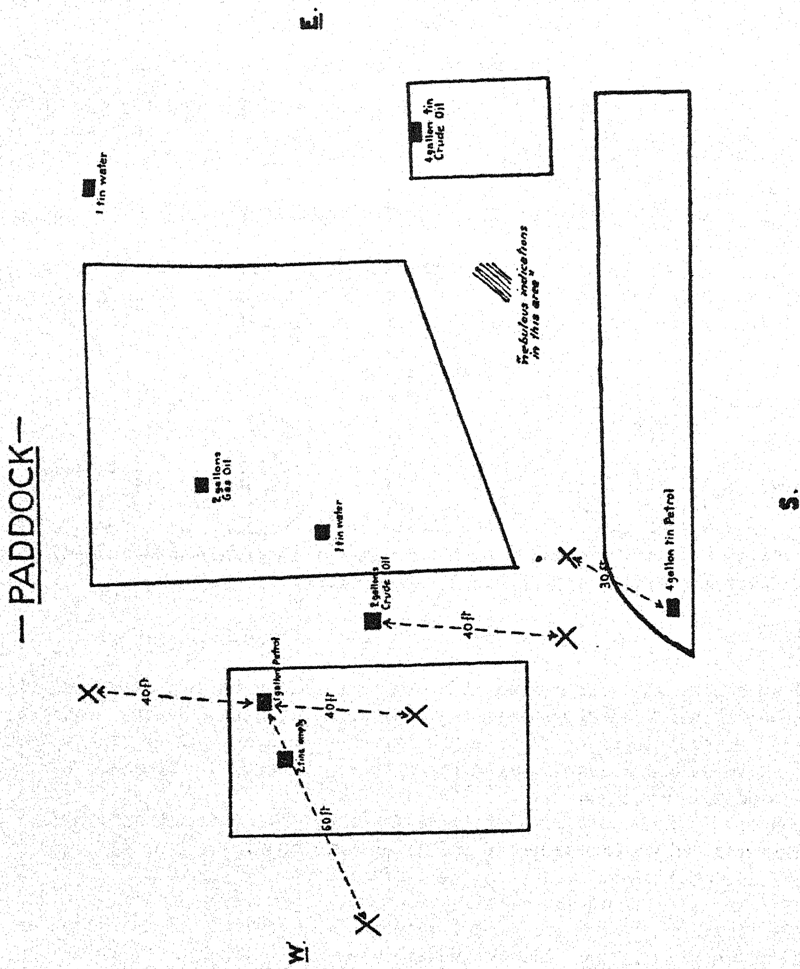


FIGURE 15.—Meadhurst oil experiments

They were taken (without being informed of the fact) within a few feet of the oil store which contained several hundred gallons of petrol and other oils, but the divining rod gave no indications at this point.

In the paddock where the buried deposits lay, the positions of these and the "locations" detected are shown in detail on the inclosed plan, together with the distances of the "locations" from the nearest actual oil deposit.

When they had completed their search the buried deposits were dug up and some of the sites they had indicated were dug up to prove to them the presence

of oil in the former positions and the absence of anything but clay in the latter positions.

Beyond quoting the valedictory remarks of one of the diviners that he "was quite at a loss to explain his failure and that he had had hardly any experience in detecting oil, as facilities in England were so limited and that what he would like would be to experiment on a known oil field" further comment would appear unnecessary.

It may be interesting to record that in a subsequent letter expressing their thanks for the facilities granted they wrote (inter alia).

1. The rod responds to substances other than oil, and further investigation will be necessary to discover what these substances are. As it is possible to distinguish between metals and water with the hazel rod, we have every hope of perfecting our methods of finding oil.

2. The barrel test was an unsatisfactory one from our point of view, as the close proximity of all the barrels and a car with petrol in the tank near by made it almost impossible to localize the exact position of the oil.

3. The fact that we failed to centralize the oil deposits in the paddock by 30 to 40 yards in every case makes it evident that our formula needs adjustment.

4. While recognizing our failure to localize small quantities of oil over a fairly extensive area, we feel that this in no way affects the possibilities of finding larger quantities satisfactorily. (Successful experiments over the L. M. S. R. oil tanks had already been carried out.)

Testing the divining rod is difficult and promises no answer that will be universally accepted, because the claims of the different diviners are so contradictory and elusive that any test may apply only to the individual tested, and perhaps to him only on a particular day. Failures are explained as due to the incompetence of the diviner tested, or to some accident which neutralized the effect of the subject sought. Thus a recent number of the Spectator (September 24, 1927, p. 458) reports that buried treasure was located by a diviner; digging for it was unsuccessful, and the diviner explained that his rod had felt a piece of ironstone found in the pit. Failures therefore are always excused and inconclusive.

VI. THE WORK OF THE ABBÉ PARAMELLE

Many of the claims for the success of the divining rod when investigated are found to depend on other methods. Thus Barrett and Besterman (1926, p. 54) claim the Abbé Paramelle as one of the most successful of French diviners. The success of that abbé in finding water in many areas of southwestern France made him a great national benefactor. The Abbé has described his method of work in his book L'Art de Découvrir les Sources, Paris (1856) which emphatically repudiates any help from the divining rod. He tested it many times; he says (op. cit., p. iii) it has a great vogue "among the ignorant" but although he tried it repeatedly across underground streams of water he never felt it make the slightest movement in his hands. He had watched many dozens of "bacillogires," including the most famous, and he declared that with them the rod moves

equally in places where there is not the slightest thread of subterranean water, as where there is some, and that in consequence it is useless as an indication of springs. Paramelle's work was based upon the combined geographical and geological conditions of the locality (e. g., ibid., pp. 303, 310, chap. 20): and he remarks that "la géognosie * * * être la science la plus propre à fournir des lumières sur les cours d'eau souterrains." He realized the main facts in the distribution of the water table, and where it could be found at easily accessible depths. He admitted that he had failures, and that therefore his method was not perfect; some failures were in-

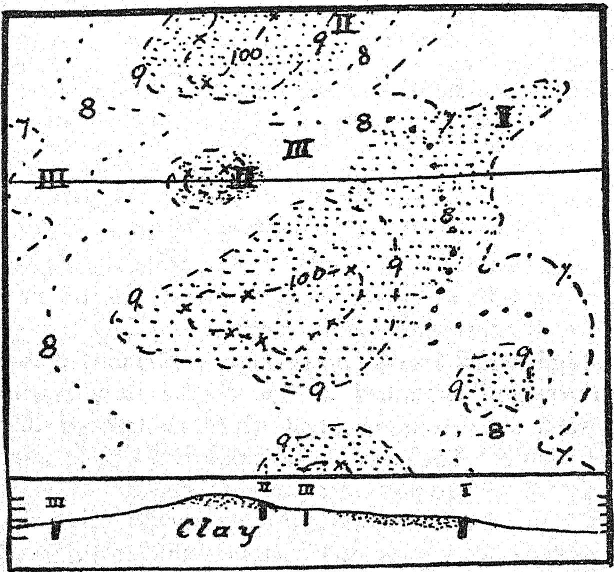


FIGURE 16.—Map and section across a gravel-capped ridge of clay. (Section is along line S—S)
Contours of 100, 90, 80, and 70 feet (lines 9, 8, 7). Gravel areas dotted; rest clay with a thin wash of pebbles in the soil. I, most likely place for well; II, less productive sites; III, dry sites. The base of the gravel is at about the contour of 90 feet on the western, and down in places to 70 feet on the eastern slopes

evitable, as there may be no sign at the surface of disturbing irregularities underground. Paramelle concluded that underlying the country is an impermeable sheet, and that wherever wells reach it they find water. His impermeable surface was not, as he thought, an undulating sheet of impermeable material, but was simply the water table. Though his theoretical explanation was defective he was generally right, owing to his insight and careful study of the district, in his inference as to the position of the water table.

VII. THE NATURE OF DIVINING

Though Paramelle scouted the use of the rod, some of the most successful diviners have apparently worked unconsciously on the same lines. Mullins was probably a man with the same type of insight,[5] but who, as an uneducated mason, adopted a less satisfactory explanation of his success than the more cultured and intelligent French abbé.

The successful water diviner is probably a quick observer, who has usually had considerable experience in the search for water, and as he goes over the ground yard by yard he recognizes clues to the presence of underground water, which subconsciously lead to some movement of the strained muscles of the hand. Under some conditions he will probably score no higher proportion of successes than a competent water expert who deliberately judges by the conditions of the ground. In some areas however there are no surface indications of underground water, and the ground has to be tested empirically as in "wild-catting" for oil, when wells have to be sunk on chance owing to the conditions of the country, or lack of time for a careful survey.

Consider, for example, the conditions on a ridge of clay capped by an irregular sheet of sand and gravel as shown in Figure 16. On virgin land it would probably be possible to recognize from the vegetation and moisture the position of underground water; but the clues are obscured or destroyed by draining and prolonged tilling which give the ground an artificial surface. Beneath it there may be water-bearing pockets of sand and gravel lying on the clay. The largest water supply would probably be found at the point I on Figure 16; a smaller quantity at the position marked II, and none at all in many places (III). If a geologist were asked to select the best place for water on this ridge he might regard the task as almost hopeless. At the end of a prolonged drought clues to the underground water might become apparent, but as the man who wants the water may not be ready to wait for 20 years the only method is to sink some trial wells. A diviner going over this ground might select a good position either by his special experience in the selection of sites for shallow wells, or by sheer luck.

In some cases the rod is claimed to act where the diviner is not guided by surface features. Thus, according to a memorandum by Mr. Little, who was agent to the Earl of Jersey, which has been kindly shown me by Sir Herbert Maxwell, Mullins was employed at Upton, Edgehill, Warwickshire; and as Lady Caroline Jenkins, Lord Jersey's sister, could not go out, and wished to see how the

[5] I am informed that Mullins sometimes made elaborate preliminary inquiries as to the distribution of wells and the persistence of pools and damp ground.

rod was used, Mullins went into the house and the rod denoted a spring under the stone paved entrance hall. He found indications at the same spot in the cellar beneath, on the first floor, and in the attic; but apparently nothing was done to prove whether water actually existed under this position.

In some cases the reputation of the diviner is made by lucky coincidences which are remembered and exaggerated, while the failures are forgotten.

The conclusions that the claims made for the divining rod are invalid, but that in areas where water is most likely to be found by "wild-catting" a diviner may be often successful, agree with the position expressed in 1897 by Sir Herbert Maxwell (1897, p. 84): "I don't believe in the divining rod, but I don't deny that its virtues are genuine; and were I in straits to find water, I should employ without hesitation a professional water finder—rod and all—if there remains one so successful as Mullins was." Since then (Ibid., Ser. 6, 1919, p. 171) Sir Herbert Maxwell has employed an amateur dowser "with thoroughly satisfactory results." His statement of 1897 exactly expresses my own opinion that though the claims of the divining rod are invalid, an expert diviner may be useful under some conditions.

In many cases the diviners' successes are due to the fact that the water table is widespread, and that in the kind of country where they are most successful water occurs everywhere. The rod is tested only where it indicates water, and not where its results are negative. Hence in such areas a high proportion of successes is inevitable. A diviner working over a level sheet of clay may feel that the prospects are unfavorable, and in his discouragement the sudden contraction of a finger is not likely to happen, and he is preserved from failure. Even under conditions to which diviners are accustomed their percentage of successes appears to be largely a matter of chance, while their efforts to find lodes, oil, and deep-seated water are so often unsuccessful that Ackermann in his Popular Fallacies (3d ed., 1923) is fully justified in including the view "that water divining is usually successful" in his list of popular delusions.

VIII. ANALOGY WITH WITCHCRAFT AND FETISH

If the power of the divining rod were limited to finding water the problem might be capable of definite proof or disproof by experiment. It should be remembered that the evidence for this power is of the same nature as that which leads its most active French champion to hold that it is capable of accurate analysis and will determine precisely the proportions of copper and zinc in a mass of brass, and that has convinced its foremost British advocate, the late Sir William Barrett, that it will read words in an envelope and predict the

results in a forthcoming examination. The divining rod will do the feats of the planchette, the spiritualistic medium, and the thought reader.

Many of the records of the success of diviners are as surprising and as inexplicable from the information given as the performances of a skilled conjuror, and as card tricks, and are as apparently convincing as many spiritualists found the feats of the Georgia Magnet and of some thought readers until more astute observers discovered the tricks. The widespread faith in the divining rod is no more proof of its truth than that in many once universal beliefs now regarded as superstitions. The belief in witchcraft was once more general than that now in the divining rod; it was accepted by parliaments and law courts as indubitable.

Thus in 1730 William Forbes, professor of law in the University of Glasgow (Institutes of the Law of Scotland, Vol. II, chap. 3, pp. 32–41), describes witchcraft as if there were no doubt of its actuality, and says that "the ordinary doom against witches is to be strangled or worried at a stake till they be dead, and thereafter their bodies to be burnt to ashes * * *." Witches were hunted down and slain in this country till the middle of the eighteenth century. Belief in fetish is now almost universal in Africa, and it appears under present conditions ineradicable, for it is maintained by the combination of the insight and special knowledge of the witch doctor, of occasional coincidences, and of skill in blurring over failures which are soon forgotten by credulous people in regard to what they wish to believe or are told to believe. Belief in superstitions is by no means extinct. Many survive and new ones arise and become entrenched by habit. It may seem disrespectful to those who believe in the divining rod to compare it to such an obsolete habit as witch hunting or to the crude ideas of primitive races, but the human mind in all people and amongst all ages has many features in common and in greatly influenced by coincidences and unexplained phenomena.

The survival of the use of the divining rod in the search for water after its many other uses have been abandoned is in my opinion due to shallow supplies of water being scattered abundantly, but so irregularly and elusively that their discovery is often a matter of chance. Some observers are especially quick in detecting the faint clues to their position, and in the areas where diviners are mostly used a large number of successes is inevitable owing to the wide distribution of underground water.

REFERENCES

Barrett, W. F. and Besterman, T., 1926. The Divining Rod, xxiii, 336 pp., 12 pls.

Culpin, Millais, 1920. Spiritualism and the New Psychology, pp. 24–33 and 34–43.

Lemoine, P., 1913. Quelques Observations sur la Baguette Divinatoire. Bull. Soc. Philom. Paris, ser. X, Vol. V, pp. 17–18; Expériences Diverses, Ibid., pp. 43–47; and with M. l'Abbé Senderens Observations sur L'Action des Sels et des Métaux, Ibid., pp. 19–42.

Mager, Henri, 1913. Les Sourciers et leurs Procédés. La Baguette, Le Pendule. vii, 314 pp.

Mager, Henri, 1920. Les Baguettes des Sourciers et Les Forces de la Nature. Guides des Physiciens et des Analystes, des Prospecteurs et des Sourciers, xi, 423 pp.

Maxwell, Sir H. E., 1897 and 1919. Memories of the Months. First ser. 1897; sixth ser., 1919; xi, 314 pp. 5 pls.

Paramelle, L'Abbé. L'Art de Découvrir les Sources. 1856. xx, 376 pp.

Sollas, W. J., 1884. Report on Wells Sunk at Locking, Somerset, to Test the Alleged Power of the Divining Rod. Proc. Soc. Psych. Res., II, pp. 73–78, and Proc. Bristol Nat. Soc., n.s. IV, pp. 116–125.

SOME PROBLEMS OF POLAR GEOGRAPHY[1]

By R. N. Rudmose Brown, D. Sc.

Since the last meeting of the British Association at Leeds, 37 years ago, the whole meaning of geography has changed. The purely empirical stages of the collection of data have largely given way to the higher stages of interpretation and explanation, and these in their turn have called for reexamination of the facts by the use of more accurate methods. An even greater change is the important place which geography has won in education. Nothing could be more striking than this advance in a generation or two unless it was the former neglect of the subject—one might say the entire omission of any geographical teaching in any grade of education—an almost incredible defect in the training of youth at a period of rapid imperial growth and consolidation. The battle is not yet won, but even if some of the universities of this country, which move but slowly, do not give geography the place it merits, it has at least a foothold in all. Geographical research and serious geographical publications have also shown an increase in recent times, though the output in this country is far too small. This, however, is neither the time nor the place to dwell on the educational side of geography. I recall these developments only because the present year has seen the passing of one who will always be associated with geographical work during the last half century, and especially the rise of geography to a place of importance in the universities and the scientific world. Sir John Scott Keltie was one of the pioneers of geographical education, and as editor of the Geographical Journal and for many years recorder and secretary of section E took a leading part in the advancement of exploration and the spread of sound geographical knowledge and research. The present position of geography in this country is largely a monument to his untiring labor, enthusiasm, and tact.

Geographical thought of to-day shows a growing tendency to lay more stress on the human interests of the subject that it did of old. As far as this leads to a broadening of the outlook in what was formerly known as economic geography, with its somewhat narrow standards of the bourse and market place, the development is all to the

[1] Address of the president of the Section of Geography, British Association for the Advancement of Science, Leeds, 1927. Reprinted by permission, with minor changes by the author, from the report of the association for that year.

good. The humanizing of the subject has done much to rob it of aridity and, by widening its scope, to bring it into close touch with other aspects of the study of man. It is a good thing for the growth of knowledge when barriers between allied subjects break down on a ground common to both. These trends in human and social geography are to be welcomed, but at the same time there is a tendency to forget that our geography must be founded on a knowledge of the surface features of the earth. The physical factors must be thoroughly understood if the superstructure of human and social geography is to have a sure foundation. This foundation can be best laid in personal experience of earth, air, and water. In other words, travel is an essential part of the training of the geographer if his work is to have any reality. The complexity of geographical values can never be gauged by any mere statistical presentment of the facts. The experience of the world that is necessary to the equipment of the geographer must be gained not merely by travel in densely populated lands, where the modern applications of science do so much to protect man from actual contact with the factors of climate, the influence of land forms, and the effect of biological distributions, but of travel by sea and in empty lands and of practical experience in exploring the natural phenomena and occurrences, of real contact with the raw materials of geography, in order to learn the elements of the science at first hand. The scientific no less than the humanistic aspects of geography must be learned by personal observation. The geographer who depends solely on maps will never understand his subject or be a source of inspiration to others. The best map is a poor substitute for reality. A year of personal experience of nature is worth the whole of a university course as a foundation of geographical study.

In selecting for the subject of my address some of the problems of polar geography I have been moved by a twofold reason. First, these problems come near to my interests by personal experiences, and I think that in a comparative lull in polar exploration in this country it is well to take stock of the problems that still await solution; and secondly, I feel that modern geographical thought, with its stress on the humanistic side, is tending to overlook the polar regions in spite of their wide geographical interest. They offer an incomparable field of observation for all sides of pure geography. From the many problems I can select only a few of importance.

THE TASKS OF EXPLORATION

To turn first to the Antarctic, there are certain fundamental problems in physical geography—problems of the nature of those which in other continents were solved several centuries ago. The broad features of the map of Antarctica are not built on ascertained fact as much as on intelligent guesswork.

The existence of an Antarctic continent is still based on circumstantial evidence, and until more than some 5,000 miles of its coast line, or only about 35 per cent of the total length, are known, direct evidence of Antarctica will be lacking. It is not a little remarkable that all the exploration of the twentieth century has merely modified the probable outline of that continent as it was predicted by Sir John Murray in 1886. He had little but the reports of Ross, d'Urville, Wilkes, a few sealers, and the *Challenger* to go on, and, mainly on circumstantial evidence, he built his Antarctic continent. The one considerable change in that map has been the curtailment of the Weddell Sea and the removal of its southern extremity some 4° north of Murray's position in latitude 82° South. But that southward prolongation of the Weddell Sea and Atlantic Ocean at the expense of Antarctica was based solely on Ross's mistaken sounding of 4,000 fathoms, no bottom, in latitude 68° 48′ South, longitude 12° 20′ West.

Most of the Antarctic "lands," and certainly nearly all those that may be classed as key positions to the coast line of Antarctica, date from last century, some of them from 100 years ago. Coats Land, Wilhelm Land, and Oates Land are among the few exceptions. Enderby Land, the one certain or nearly certain land in over 3,000 miles of hypothetical coast line, has never been seen or seriously searched for since Biscoe found it in 1831. It should be the base of an expedition that is prepared to work westward. Heavy ice congestion so far found by all vessels that have tried to push south between Enderby Land and Coats Land suggests that this stretch of coast line will have to be put in by sledge journeys along the edge of the ice cap. The western shores of the Weddell Sea are another ice-girt region which no ship has been able to penetrate, a region of dangerous ice pressure. Here, too, the advance must be by land journey, but it should be relatively simple, since accessible bases are known in Oscar Land and adjoining parts of Graham Land. Lastly, there is the great gap south of the Pacific between Charcot and Edward Lands, which leaves ample scope for an attack from both ends. A minor problem in the outline of Antarctica for an expedition based on Edward Land is the determination of the eastern side of the Ross Sea and the elucidation of Amundsen's sighting of land to the south of Edward Land, the appearance of land which he called Carmen Land.

But even more important than the discovery of the "missing" stretches of the Antarctic coast line—a mere matter of descriptive geography—is the explanation of the structure of the continent and its former connections with other lands of the Southern Hemisphere. The problem is made more difficult of solution by the immense covering of ice that completely hides the underlying rock in

most parts. Detailed exploration has so far concentrated on the two more accessible coasts of Antarctica—those of Graham and Victoria Lands. In fact, one might reasonably argue that there has been too great a concentration of interest on those coasts, on the part of well-found expeditions, to the neglect of unknown or little-known areas more difficult of access but promising more striking discoveries. That has been due, no doubt, to the one, Graham Land with its islands projecting northward into open sea and lying near civilized lands, and the other, Victoria Land, offering the most promising point of departure for sledge journeys to the pole. However, now that the South Pole has been reached, the temptation to focus effort on the best available base for that undertaking has gone, and the explorer's energy of the future is more likely to be expended in directions more profitable to the advancement of knowledge.

Graham Land, for we discard the awkward title of west Antarctica, and Victoria Land, or more strictly South Victoria Land, are both regions of lofty mountain ranges, but apparently of contrasted structure and diverse origin. The ranges of Graham Land, often called the Antarctic Andes, in stratigraphy and structure, as well as in their eruptive rocks, bear so close a resemblance to the Cordilleras of South America that there can be no reasonable doubt that they were at one time connected and are in fact disunited parts of the same foldings. Nor does it appear doubtful any longer that the line of former continuity can be traced by a submerged ridge on which stand relics of the chain—in the South Orkneys, the volcanic south Sandwich group, and South Georgia, extending in a great arc between Trinity Land and Tierra del Fuego and sweeping well to the east of Drake Strait. There is no doubt of this line of connection, but we are still uncertain if South Georgia, and even more so, if the Falklands are really fragments of the arc or relics of a lost south Atlantic Land.

The Antarctic Andes, or Southern Antilles, have been traced southeastward but lost sight of at Alexander Island and Charcot Land, which in all probability are parts of the same formation. The great problem of the Antarctic is what happens to these ranges. On the opposite, or New Zealand, side of the Antarctic the great fault ranges of Victoria Land show little if any resemblance in structure and origin with the Antarctic Andes. A great horst capped with horizontal layers of sandstone, probably of Permo-Carboniferous age, is associated with much evidence of volcanic activity, and seems to rise from a great peneplain of crystalline rocks which underlie the whole of that side of the Antarctic ice sheet.

The structure of the Victoria Land edge of the Ross Sea is reminiscent of Tasmania and eastern Australia. and the suggestion of

former continuity across the southern ocean receives further support from our knowledge of submarine relief between Antarctica and Australia, especially the work of the *Aurora* expedition.

The relationships between Antarctica and South Africa are still very obscure, since the African quadrant of the Antarctic, both by land and by sea, remains one of the least explored parts. It will prove a fruitful area for an expedition to tackle.

It is unnecessary to enter into the details of the arguments in geomorphology bearing on the relationships of the two contrasted sides of Antarctica. I have recently expounded these at greater length elsewhere (The Polar Regions, R. N. Rudmore Brown (1927)). Only further exploration can solve the mystery. We must go and see if we want to know. But it may be of interest to state the possible solutions.

One suggestion is that the horst of Victoria Land is continuous with the Antarctic Andes. Certainly the direction of the Maud Mountains to the south of the Ross Sea supports this view, and evidence of great faults bounding the Andes may show that those ranges after all are not entirely different in nature from the ranges of Victoria Land. A second suggestion is that the Antarctic Andes reappear in the Ross Sea in the old crystalline rocks of King Edward Land—which as yet are but little known—and that these were once continuous with the folds of New Zealand. If this be true, the ranges of Victoria Land and the Maud Mountains probably swing across to Coats Land and may cause those vague shadowy shapes that a few of us who have seen Coats Land believe to exist in its far interior. Nothing is known at first hand of the structure of Coats Land, but rock fragments dredged in the Weddell Sea, and presumably derived from Coats Land, suggest a closer relation with Victoria than with Graham Land.

In any case, it looks probable that our knowledge of Antarctica confirms the growing belief that the Pacific basin is girdled by a ring of fold mountains marking the course of a system of geosynclines. The remains of the borderlands of this Pacific geosyncline may possibly be found in small islands in that mysterious ice-bound region to the north of Edward Land which no ship has been able to penetrate.

In the face of these great problems in exploration, it seems trivial to speak of the minor ones that await solution in the south. Reference, however, may be made to the desirability of measuring an arc of meridian in a high southern altitude. F. Debenham has pointed out how Victoria Land lends itself to this task.[2] I have not time to dwell on the problems of meteorological exploration and can only

[2] British Antarctic Expedition, 1910–13. Report on Maps and Survey, 1923.

point out that much has yet to be done in explaining the peculiar Antarctic blizzards which rank among the fiercest winds on the face of the globe. G. C. Simpson has given an explanation of these in the Ross Sea, but are the blizzards of Wilkes and Coats Lands, which occur under different topographical conditions, amenable to the same explanation, or has W. H. Hobbs found the solution in his theory of strophic winds associated with glacial anticyclones, a theory which he applies also to Greenland, where he is at present investigating it?

Recent observations in Northeast Land, Spitsbergen, confirm the association of this general air circulation with a dome of ice-covered land, but, as Sir Napier Shaw, L. C. W. Bonacina, and others have pointed out, we require another term than anticyclone for this state of affairs, since the high pressure is only a shallow surface effect resulting from local conditions and not a true anticyclone developed as the outcome of general atmospheric circulation independent of local topography. Even the qualification of "glacial" does not remove a possible confusion of ideas. The supply of cold air from polar regions toward lower latitudes appears to be independent of pressure, inasmuch as the winds are katabatic winds flowing down the slope of high land. It is orographical relief and not pressure which supplies the driving force of the cold air currents of the polar front.[3]

A further important meteorological problem, with strong geographical bearings, is the alimentation of the ice sheet. We know that it is wasting by the calving of icebergs, by surface ablation, and other processes, and that it has shrunk considerably since its Pleistocene maximum, but we are at a loss to explain satisfactorily how the precipitation in the heart of an anticyclone can ever have been sufficient to allow such an ice sheet to grow. There is every reason to believe that during the great Ice Age ice sheets did not develop over the Arctic islands of Canada or over most of Siberia. The temperatures were low, but moisture was insufficient. And yet in the Southern Hemisphere the ice grew in the heart of a vast high-pressure area.

Still another problem is that of oscillation of climate as expressed by varying amounts of sea ice and variations in the intensity of currents. R. C. Mossman and others have shown that there is a correlation between certain Antarctic records and those from places in the Northern Hemisphere. There seems to be every likelihood that before long general weather forecasts of real value will be possible for

[3] W. H. Hobbs, The Glacial Anticyclones (1926). A valuable symposium on Arctic meteorology is the collection of papers read at the first meeting of the International Society for the Exploration of Arctic Regions by Airship, published in Petermann's Mitteilungen, Ergänzungsheft 191 (1927). A chart shows the route of the proposed expedition and the location of observing stations.

some months ahead.[4] At Buenos Aires, for example, the high correlation coefficient of +0.88 is reached when the summer rainfall there is correlated with the temperature of the South Orkneys for the winter that began three and a half years earlier. In fact, statistical correlation indicates that a very cold winter at the South Orkneys will be followed after an interval of three and a half years by a drought over the Argentine cereal belt; a very mild winter, after the same interval of time, by bountiful rains.

Lastly, there is great need of oceanographical work in high southern latitudes. This branch of research has been overlooked by most expeditions in their hurry to reach their southern bases. Certainly in the tempestuous seas of the fifties and sixties of southern latitude it is uncomfortable and trying work and exasperating in delays and loss of apparatus. The employment of echo sounding should, however, make it both easier and more accurate.

There has been much careful and intensive work in the Antarctic during this century, indeed since the voyage of the *Belgica*, but it has merely touched the fringe of what there is to be done. The recent work of the R. S. S. *Discovery* in the seas to the east of South Georgia should fill gaps in existing knowledge of the southern ocean, but details are not yet available.[5]

Antarctic expeditions are costly, far more costly than expeditions to the Arctic. It is unlikely that an impoverished Europe will be able to find the necessary funds for years to come. We must look with hope toward the great new nations of the Southern Hemisphere, some of whom have already shown a marked interest in the Antarctic. It will be a sad day when man is so free from curiosity about this earth that the last mysteries of its surface are not probed because the task demands enthusiasm and money.

No pioneer problems of equal magnitude await the explorer in north polar regions. There is small likelihood that any new land of importance remains to be discovered. There is certainly no "polar continent." However, there are gaps to be filled. Nicholas Land, found by the Russians to the north of the Taimir Peninsula in 1913, has still to be investigated. Its full extent and its relation to other Arctic islands are unknown. Northwest of it the Arctic Ocean has never been penetrated except by the drifting *St. Anna* in 1912–1914. We hope that Russian investigators of the coast of Siberia will include Nicholas Land within their scope of work.[6]

---

[4] Southern Hemisphere Seasonal Correlations, R. C. Mossman. Symons Meteorological Mag., 48, 1913; and The Climate and Meteorology of the Antarctic and Sub-Antarctic Regions, R. C. Mossman, Journ. Scot. Met. Soc., 1918, pp. 18–29.

[5] *Discovery* Expedition. First Annual Report, H. M. S. O., 1927.

[6] For the latest map of the Russian Arctic coasts see The Russian Hydrographical Expedition to the Arctic, N. A. Trausche, Geog. Rev. (New York), No. 3, 1925.

The Beaufort Sea to the north of Alaska and to the west of the Canadian Arctic Archipelago, across which Amundsen, Ellsworth, and Nobile made their daring flight in 1926, has never been penetrated. Its exploration is required in the interests of Arctic oceanography, and the mystery of Peary's Crocker Land should be finally solved. Tidal observations of the *Maud* expedition off the Siberian coast have been shown by H. U. Sverdrup to negative the probability of extensive land to the north of Bering Strait and Alaska. Yet the five hours' retardation of the tidal wave in reaching Point Barrow, Alaska, from the north, compared with its time of arrival at the De Long Islands, northeast of the New Siberian Islands, indicates the possibility of small islands in the Beaufort Sea or, more probably, merely the existence of shallow water.[7]

In addition to Crocker Land, several elusive lands have been reported in the Arctic Ocean, and from time to time have found their way on to maps, in most cases only to disappear when confirmation of their existence was not forthcoming. Experience has shown that visibility plays strange tricks on the observer in polar regions. A snow-covered land may merge completely in the background of sea ice and gray sky or an unsuspected local fog bank may blot it out at a few miles distance. No polar land can be said to be disproved until its site has actually been sailed over. And even then one may ask, Was the reputed site a true one? Its position may have been guessed from a single long-distance sight, and guessed perhaps on a basis of faulty observations. The drift of the *Fram* and the voyages of the *Taimir*, *Vaigach*, and *Maud* may be held to have disposed of Sannikov's Land to the north of the New Siberian Islands. Keenan Land to the north of Alaska has also gone. There is little probability of Andrejev's Land being a reality, but no ship has yet penetrated the area of sea where it was reported to lie (1763) to the west of Wrangel Island, in about the meridian of 170° W., between latitude 72° and 73° N. There between the tracks, on the south of the *Taimir* and the *Vaigach* and on the north of the *Jeannette* and the *Maud*, occurs a region of heavy impenetrable pack. Kellett's Plover Land, a degree or two north of Herald Island, north-northwest of Bering Strait, was removed from the map as a result of several later voyages of vessels that sailed over its reputed site and saw no land. But a shadow of doubt has fallen on these corrections since in 1914, from the high eastern end of Wrangel Island, the appearance of land was noted on several days away in the east-northeast beyond Herald Island in an area of the sea where the water on the continental shelf is known to be very shallow. This appearance was given the name of

[7] The Tides on the North Siberian Shelf. H. U. Sverdrup, Journ. Wash. Acad. Sci., 16, pp. 529–540, 1926. The flight of G. H. Wilkins in 1928 practically disproved Crocker Land.

Borden Land and may, if it really exists, be the long-lost Plover Land. Inaccuracies in latitude and longitude are easily made in hasty observations in high latitudes.[8]

An even more alluring mystery can be solved only by the exploration of that part of the Arctic Ocean between Spitsbergen and Franz Josef Land from latitude 80° to 84° N. There is no record of a ship traversing it, and there is more than one report of high land seen to the northeast of the Spitsbergen group. This, if it exists, is not Giles Land, which is farther south and relatively low, but it may be an outlying island of the Franz Josef group.[9] There are, however, other problems of great interest in the north. The extent and bottom features of the Arctic basin are still little known, and only in a few places has the width of the remarkable continental shelf been defined. North of Alaska, the New Siberian Islands, and Spitsbergen, the edge has been charted and with less certainty north of Ellesmere Island and the Franz Josef group. In other parts it is still vague. When evidence is scanty it may seem rash to speculate on the origin of the Arctic Ocean, but there are many features about the Arctic basin which suggest that it is not comparable with the basins of the Atlantic and Pacific, and that it is possibly a relatively new feature of the earth's crust. On the other hand, the discovery in East Greenland of extensive series of Paleozoic rocks seems to dispose of the idea of a former Arctic continent of great extent.

Another problem of importance and far-reaching influence is the mysterious fluctuation in the extent of Arctic sea ice. The fluctuations appear to be cyclic rather than progressive, but so far defy satisfactory explanation. C. E. P. Brooks has recently pointed out the influence of the amount of ice in the Labrador and East Greenland currents on pressure distribution and consequent amount of precipitation in the British Isles.[10] Here at least is one direct link between the Arctic and the most important factor in our climate. But until we know more about Arctic climatic conditions and the distribution of ice in the Arctic basin, we are not likely to find the cause of these fluctuations.

---

[8] Plover Land and Borden Land, V. Stefansson, Geog. Rev. (New York), April, 1921. It may be noted that Keenan Land is the only one of these doubtful lands that Stieler retains in his most recent Nordpolar map.

[9] Giles Land (also Gillies Land or Island), discovered in 1707, was rediscovered by J. Kjeldsen in 1876 and explored by A. G. Nathorst in 1898. It lies in about latitude 80° N., due east of Spitsbergen. This is where Giles himself placed it. The area of sea indicated was crossed by the Soviet icebreaker *Krassin* in her search for the crew of the wrecked airship *Italia* in 1927. No land was seen.

[10] See the annual report on The State of Ice in the Arctic Seas, published by the Danish Meteorological Office from all available records. It is necessarily incomplete and leaves great areas untouched, especially the seas north of Asia and the Beaufort Sea, where observations are most needed. C. E. P. Brooks, Pressure Distribution Associated with Seasons in the British Isles, Quart. Journ. Roy. Meteorol. Soc., 52, 1926; W. Weise, Polareis und Atmosphärische Schwankungen, Geogr. Ann., 6, p. 273, Stockholm, 1924.

24034—29——24

Facts so far available point to a rotary surface movement with overflows from an overcharged Arctic basin, by the Greenland Sea and other less important outlets. This movement may account for the tendency of ice-bound vessels in the Arctic basin to take a peripheral drift, as the *Fram*, *Jeannette*, *Karluk*, and *Maud*. It may also explain the relatively smooth and unrafted ice reported from the vicinity of the Pole. Again, the heavy ice to the north of Greenland, which proved so baffling to the Nares expedition that it received the title of paleocrystic ice, may be due simply to the heaping and rafting against the land of the pack that has been swept past the overflow of the East Greenland current. It can not, however, be said that this circulation is proved. Many more observations are required.

Fluctuations in the amount of ice in the overflow currents may well be due to variations in the strength of these currents. These variations may be associated with departures from the normal in the amount of water poured into the Arctic basin from the great Siberian and American rivers, which in its turn depends on causes far removed from Arctic regions. The complexity of the problem is almost baffling, but even before the chain of cause and effect is traced useful work could be done in looking for correlations.

METHODS OF EXPLORATION

Every age has seen a change in the methods employed in polar exploration, and it may be of interest to review the resources of the explorer in the light of modern knowledge. In the early days of Arctic exploration attempts concentrated on the hope of finding an open sea route to the north. Hence the lines of attack were by the two gulfs of warmth due to the northward-flowing waters of the North Atlantic drift, Hudson Bay with Davis Strait, and, particularly, the Greenland Sea. By the early part of the nineteenth century the hopelessness of advance by that means was realized, and not long after the prospect of an open-water route across polar regions in a lower latitude faded. Then came the period of probing the unknown north from a land base in a high latitude from which sledge journeys could take their start. Eventually the North Pole was achieved by this means, long after Nansen, throwing aside all accepted canons of polar travel, had found a new and daring method. Instead of avoiding besetment he courted it; instead of battling with the floes he made use of their drift.

Meantime, the age of steel prompted a new method of attacking ice. The ice breaker was tried away back in 1899, when the *Yermack* made an experimental voyage to the northwest of Spitsbergen. On more serious exploration the Russians used ice breakers on the

Arctic coast of Siberia in the years immediately before the Great War. But, though an ice breaker can deal with ice several feet in thickness, it can not dispose of that ice; if the pack is close the ice breaker will sooner or later become beset and helpless and at the mercy of pressure due to wind and current. Even a powerful ice breaker could be crushed by such enormous pressure. Only a ship that rises is safe. For keeping harbors open and smashing new ice the modern ice breaker is valuable, but it has no place in serious polar exploration.

The polar pack ice is still the most formidable obstacle that the explorer has to face. It may provide a laborious but uncertain road for sledging, but because of its drift before current and wind it is always dangerous to vessels, except those built on lines that defy crushing. Such a ship can drift in safety with the moving pack, but seldom can retain its freedom of action. Man to-day is little better able to penetrate heavy pack than he was 300 years ago. The ice-infested seas are still barred to commerce and the only advance that has been made is in a knowledge of the position and drift of the ice, so that navigation of the edge of the pack is relatively safe.

And now another method of advance has been tried. The baffling pack ice can be avoided by progress through the air. Air transit in the Arctic is not new; as long ago as 1897, S. Andrée made a hazardous and fatal attempt, but in those days the aeronaut could do no more than drift, and Andrée unfortunately drifted to destruction. In recent years the airplane has appeared in the Arctic, and Amundsen and Nobile have used the airship. It was inevitable that aviation should be tried in high latitudes, if for no other reason than its spectacular daring, but so far its success has not been marked. That, however, does not necessarily imply that aviation is never to be a serious help in polar exploration. Amundsen's flight in the *Norge* gave a probable confirmation of what had already been deduced from indirect evidence. He found no land where none was expected. He saw nothing but ice-covered sea. Moreover, a rapid flight over snow-covered land, even if the eye could distinguish that surface from ice-covered sea, would tell little of importance. Byrd's flight to the pole and back was of even less value to exploration, for on his track there was no possibility of land. The kind of exploration that is now required entails patient observation and accurate measurement. A quick-moving machine can not help in this, and there is always the probability of mist to hamper the value and imperil the success of aviation in the polar summer. Amundsen himself admits that owing to "a tremendous sea of fog, in some places of extraordinary density" in the Beaufort Sea, he may have passed over islands of low altitude without seeing them, so that on the only part of its

course where land can possibly exist the flight of the *Norge* has left us where we were, and the field is clear for the next explorer.

Even for reconnaissance the airplane has doubtful value, so much depends on ground organization, which never can be perfect in polar regions, and there is the even greater difficulty of satisfactory landing places. On the long flight of the *Norge* from Spitsbergen to Alaska not a single landing place was seen, at least not one suitable to the eyes of those who had experience of polar ice. Pack ice rarely offers the requisite surface, and certainly can not be relied on to do so, while among drift ice the necessary expanse of open water is seldom available for a hydroplane. The use of a lead may prove fatal by the ice closing in on the machine. In his first attempt on the North Pole in 1925 Amundsen very nearly lost his machines and the lives of his expedition by landing in a pool of water. As it was, he had to abandon one machine, and it was only by his skill and determination that he retrieved from disaster what was a fiasco as far as scientific exploration was concerned, except for one sounding.

It should, however, be noted that G. H. Wilkins, from his flying experience north of Alaska, maintains that landing places on pack ice are numerous. He certainly made safe landings on two occasions without much difficulty.

For the transport of stores, equipment, and collections the airplane has little value because its use introduces an element of grave uncertainty into the work of the expedition. The explorer must be prepared for the journey on foot or by boat if his airplane fails him. He must carry the necessary equipment, or he is incurring a foolhardly risk. And in that case why take the airplane at all?

In one respect, however, the airplane can be successfully used in polar work, that is in aerial survey of difficult country that lies within reach of a base accessible by sea transport and provided with a good landing place. The value of aerial surveys has been proved in many parts of the world. The survey of the Irrawadi Delta in a few weeks instead of the two or three years that ground work would have entailed, is a case in point; and J. M. Wordie has instanced the eastern edge of Greenland as a country where the aerial surveyor could rapidly make a map of the most rugged and untraversable country. The investigation of the movement of pack ice in Hudson Strait, undertaken this year by the Canadian Government, is another instance of the value of the airplane in Arctic work.[11]

[11] Few men have flown in the Arctic. Some of the most valuable fruits of experience will be found in G. Binney's With Seaplane and Sledge in the Arctic (1925), and R. Amundsen's My Polar Flight (1925) and The First Flight Across the Polar Sea (1927). This address was written before the memorable flights of G. H. Wilkins in 1928 in both the Arctic and the Antarctic. Those flights do not contradict the general conclusions in this address.

In the Antarctic, where I have pointed out the pioneer explorer still has ample scope, long-distance flights may be of some value. The ice cap offers the prospect of better landing than the pack ice. Yet in view of its great expanse there is even less chance of retreating on foot after a forced descent. The Argentine aviators, A. Pauly and Zanni, propose to fly across Antarctica from Graham Land on the Weddell Sea to Victoria Land or the Barrier edge on the Ross Sea next December. Their success depends largely on the efficiency of their machine. A forced landing will probably mean their total disappearance, but a successful flight will certainly give some broad results of value, although tantalizingly vague and inconclusive, as to the structure of Antarctic. An American flying expedition under Commander R. E. Byrd to the Ross Sea has also been announced.

Probably some reliable form of mechanical traction for sledges would be more serviceable than aviation in serious exploration. Dogs are useful for traction to men who are accustomed to manage them, but their area of action is limited by the amount of food that they require. Man haulage gives longer range, but is terribly destructive of human energy. Machine-drawn sledges would require fuel, but the carriage of light fuel would not seriously impede their radius of use. The whole problem of mechanical transport really turns on its reliability. So far its use has been a failure. But we live in an age of rapidly increasing mechanical skill. Yet is it ever safe to put absolute trust in a machine?

There must be risk in all exploration, but can one ever reduce the risk of the motor sledge breaking down to reasonable limits? The wear and tear is tremendous, far greater than in a motor gliding smoothly through the air. On a short journey a breakdown would be merely a nuisance; on a long journey, far from the base, it might well be fatal. In short, while a man knows his own capacity he can never have an equal faith in the capacity of the machine. The use of motor sledges is bound to come, and they will be very useful, but undoubtedly they will introduce an element of uncertainty in the journey. They will increase the chance of success as well as the risk of failure.

Quite apart from means of transport, polar exploration has undergone changes in recent years. Equipment is better than it was of old; food is better preserved, more varied, and more in accordance with human requirements. But the greatest change has come in the passing of the fear of the Arctic. Men who know the polar regions are no longer frightened of the cold and darkness and no longer shun the food resources of polar lands and seas. The terror that the Arctic inspired was a legacy of medieval superstition; the outcome, like all superstitions, of ignorance. Before Europeans had ever experienced a polar night, they thought that it must be fatal. The old

whalers in Spitsbergen could conceive of no greater horror than to stay there during the winter. There is a tale that an attempt to found a winter settlement to guard the whaling stores failed because the settlers, who could be obtained only by releasing convicts, begged, on seeing Spitsbergen, to be allowed to return to gaol and even execution rather than stay and endure the unknown horrors of an Arctic night. The legacy of fear is still part of Europe's regard for polar regions, but the explorer has conquered it and he knows well that it requires no particular courage to face the polar climate. Fifty years ago expeditions dug themselves into winter quarters and stagnated half the year. Nares considered it cruelty to ask his men to sledge before April. But now winter is regarded by the explorer, as by the Eskimo, as a useful period for sledging. The snow and ice have better surfaces and the temperatures are not uncomfortably high.

Even more striking is the lightness of the modern explorer's equipment compared with the heavy load of old. In "living off the land" and traveling lightly and quickly without supporting parties and depots of stores, John Rae set an example 70 years ago which was later followed by Nansen, Isachsen, Stefansson, and others. On a purely meat diet man can maintain his health and vigor for weeks and months. If he can so break with his habits as to give up tea, coffee, sugar, bread, and tobacco, his equipment in many of the more favored parts of the Arctic can be reduced to personal clothing, sleeping sack, rifle, and ammunition. But the practice can not everywhere be adopted. Even its more ardent advocate, Stefansson, had to abandon it at times and in certain gameless areas. The Arctic is not friendly everywhere; it can be very unfriendly, and it is rash to generalize from the most-favored regions.

The Antarctic may be termed invariably hostile except for its penguin rookeries tenanted for only a few weeks a year. Once the ship is left in the Antarctic, a provisioned base is absolutely essential. Journeys without stores would in all probability prove fatal. Antarctic travel must be mainly over the land ice, which is wholly devoid of any living thing. The sea ice, in the lack of landlocked channels and basins, seldom affords a road for the traveler. Not only is it very rough, piled and rafted, but it drifts even in midwinter. Seals are seldom accessible to the Antarctic sledge traveler, for comparatively rarely can he descend from the ice cap to the sea ice owing to the steep ice cliffs.

Even in the Arctic it must be remembered that living off the land demands the sacrifice to hunting of much time that could be more profitably employed by a party of scientific men, while if hunters are specially attached to the expedition, in addition to the scientific staff, there is the liability, even certainty, of a large party exhausting the game in any one locality and requiring to move on in search of food.

Such contingencies would be detrimental to the real aims of the expedition. Without neglecting the valuable resources of sea and land, it will seldom be wise for an exploring party to dispense wholly or even largely with transported stores, however great the temptation may be to lighten the load and thus widen the area of activity. In a forced march of retreat, however, ability to find food and confidence in its value are important.

A greater terror than the danger of lack of food in polar exploration used to be the prospect of scurvy. That has practically gone. Scurvy used to be considered inevitable sooner or later. No expedition entirely escaped it, and nearly all lost men and power of work through its ravages. Much of the bad reputation which the Arctic gained in the past must be attributed to scurvy. And its prevalence on the Franklin expedition—it was really attributable for its total loss—and on the Franklin search expeditions gave a grim aspect to polar travel which it has not yet lost in popular opinion. There is no excuse for the occurrence of scurvy on an Arctic expedition to-day, although there may still be risk of it on a journey over the Antarctic continent, but its total disappearance from the casualties the explorer has to face can be a matter now of only a few years. The advance of physiological science will no doubt result in scurvy being classed with the rare or extinct diseases.

Thus, as knowledge grows, the power of the explorer increases, and the old-time hardships that we read of seem curious fantasies or epics of heroic men battling blindly with ignorance.

When Europe came to realize that there were no commercial sea routes across the Arctic Ocean, a new motive, other than commercial gain, fortunately inspired polar endeavor or it might have ceased altogether. That aim was found largely in the attainment of the pole. The actual attainment was of no scientific importance, but it was of value as an ultimate objective and the lure of the pole led men onward into the unknown, and thus it served science in its day.

Once the poles were gained, that lure vanished. There is to-day as much need as there ever was for the penetration of the Antarctic continent along a score of meridians or of the passage toward the North Pole by more than one route across the Arctic Ocean. But the feat has been accomplished, and so the aim no longer fires the popular imagination. It fails to serve as a bait to secure the necessary financial backing for a well-found polar expedition. It may be regrettable, but it is certainly true, at least in this country, that an expedition with purely scientific aims and no sensational journey or feat in its program must appeal in vain for funds. These are seldom forthcoming for the advancement of pure knowledge. Scott and Shackleton fully realized this in putting their Antarctic plans before the public. Bruce, on the other hand, deploring the necessity, refused to

accept it. And after all, high endeavor in the strenuous field of polar exploration has a value of its own, even if that value be not scientific. It is, however, unfortunate that in recent years more than one expedition has been successful in raising funds, and others have attempted to do so, for programs that were little else than spectacular and bore the smallest prospect of useful work. This is to be deplored because it diverts funds from earnest work and sometimes even brings discredit on polar exploration. Every serious worker in polar research must regret the entry in the field, from time to time, of men who have few qualifications for the task and see in it merely an opening for spectacular notoriety or a measure of financial gain by means of dramatic cinematograph films and newspaper articles.

I have tried to show that even if pioneer journeys have not ended, exploration is entering on a new phase, that of fixed stations of at least a year's duration and preferably longer, where detailed researches in meteorology, biology, and other branches of science can be pursued. Many years ago Denmark led the way with such a station at Disko in Greenland. Norway has at least one permanent meteorological station in Spitsbergen, but the only permanent station in the Antarctic regions is the Argentine Observatory at the South Orkneys, founded in 1903 by W. S. Bruce, unless we look upon the temporary marine laboratory of the Falkland Islands government at South Georgia as an Antarctic station. There is room for more, and it is to be hoped that some day there will be at least an oceanographical laboratory in the Arctic land, only a few days' sail from our shores, western Spitsbergen.

Meanwhile, we welcome the stimulus to real polar research afforded by the Polar Research Institute at Cambridge and the new interest in polar exploration evinced by the recent successful Cambridge expedition to east Greenland and no less valuable Oxford expedition in Northeast Land two years earlier. Such expeditions fill in details that were overlooked in the age of pioneer journeys when the scientific problems awaiting solution were not formulated. They can in one season accomplish as much as the older expeditions did in a year. We may look for useful work from the Cambridge expedition now engaged in the survey of the little-known Edge Island, Spitsbergen. Nor must we forget that for some years now the Royal Canadian Mounted Police in their patrols between their far-flung Arctic posts have been quietly conducting useful explorations. The excellent work of the Danes in Greenland should also be noted, and especially the exhaustive work on the Eskimo which K. Rasmussen has extended westward to Bering Strait. Norway also is filling in the details omitted by earlier explorers in Spitsbergen and publishing a series of valuable monographs on that country.

SETTLEMENT OF POLAR LANDS

During recent years territorial claims have been made to all parts of Arctic regions that were not formerly subject to sovereignty, and even in the Antarctic great dependencies have appeared. This is an expression of the growing belief that polar regions are not merely desert wastes but have some economic resources of value to man.

Fur and oil first brought Arctic regions into the areas of commerce. The advance by sea, as with the explorer searching for a sea route to the east, was naturally by the two gulfs of warmth into Davis Strait and the Barents Sea. The most approachable Arctic lands were first exploited and first devastated by hunter and trapper. Thus Greenland and Spitsbergen have suffered first. The land approaches were naturally where continental land projects farthest north, Canada and Siberia. Those routes led to a later advance of the trapper, but to as ruthless an exploitation when once it began. Hunting can not last; it is rapidly failing. Modern weapons are too effective, and already the Eskimo are suffering after a brief period of prosperity. But since the market for furs will continue and even grow, and since the best furs will always be Arctic winter skins, the demand must be met by breeding fur animals. Climate exercises a rigorous control on the commercial value of the furs, a control from which there is no escape. Under wise game laws the Arctic lands and seas may produce a steady crop of furs, but the new form of exploitation will be rather an aspect of stock raising than of hunting. Even the hunting of sea mammals will suffer eclipse as the civilization of machines advances. The whaler has now deserted most Arctic seas, the sealers are fewer, and the walrus hunter has nearly exterminated his prey. The addition of motor power to sloops has enabled the Arctic hunter to extend his area of operations by penetrating the pack farther than sail would admit. Arctic animal life has suffered as a result—as for instance, the inroads on Spitsbergen reindeer in their relative safe sanctuaries on the north and east.

Of all Arctic animals, at least of those that have a commercial value at present, the polar bear will endure longest, not because he is least desired, but because he is a sea mammal who lives in the inner fastnesses of the polar pack and can be hunted only on its fringes.

Exhaustion of game leads to a decrease in the number of hunters. As far as this decrease concerns temporary hunters from the south, it may lead to a slow revival in resources; but as regards the permanent inhabitants of Arctic America, the Eskimo, it has serious effects. Their standard of living is reduced, want appears, and their

culture and their race languish. A century ago the Eskimo had struck a balance between numbers and resources. They were perfectly attuned to their environment even if their area of settlement oscillated a little on the confines where game was liable to fail as numbers increased. Then the introduction by Europeans of more effective weapons upset the balance. So nicely adjusted was their equilibrium that the looting of iron from McClure's abandoned ship, *Investigator*, was probably the cause of the virtual extermination of the musk ox on Banks Island and its consequent abandonment by the Eskimo. The exhaustion of game brought the Alaskan Eskimo to the verge of starvation a few years ago, and if the United States Government had not intervened might have wiped out that branch of the race.

The resources of the Arctic are not, however, limited to hunting, even if we include with hunting the breeding of fur-bearing animals. Outside Greenland, with its ice sheet covering 94 per cent of the island, a comparatively small area of Arctic lands at present bears permanent ice. The Canadian Arctic islands are free except small ice sheets in the east, in parts of Ellesmere and Baffin Islands; the Eurasian Islands have more, though there are large free areas in Spitsbergen and the south island of Novaya Zemlya, while the whole of the mainland areas of Siberia, Alaska, and Canada, which can by any stretch of meaning be called Arctic, are free from permanent ice. Beyond the northern limit of trees there may be said, at a rough estimate, to be about 5,000,000 square miles of ice-free land, or considerably more than the total area of the United States. Most of this is covered with some kind of tundra. The mainland and some of the island areas have a close covering which in favored places may attain a luxuriance and vigor of growth which has little relation to latitude and contradicts all preconceived notions of Arctic productivity. Thus western Ellesmere Island and northwestern Greenland are noted for their vegetation. In other places the plant covering is open, and on some of the islands there are areas which are practically desert and bear only a few mosses, lichens, and scattered plants.

These tundras are the natural grazing grounds of caribou, reindeer, and musk ox. The musk ox go farthest north, being found even in Ellesmere Island and northern and eastern Greenland, and they are confined to the American Arctic. Neither animal—for of the three caribou and reindeer are essentially the same—leaves the Arctic in winter. They are natives of the north and do not suffer from the winter cold and light snow. Their only enemy besides man is the Arctic wolf. It preys successfully on the reindeer and is less likely to attack the musk ox, which not only can fight the wolf with

its sharp horns but finds safety in numbers. The wolf seldom cares to attack a herd.[12]

Musk ox and reindeer are complementary to one another in their food requirements. The reindeer prefers grass and willow shoots in summer and the lichens, known as reindeer and Iceland moss, in winter, while the musk ox eats grass and shoots at all seasons. Now grass and shoots are more abundant than lichens on the Arctic tundras, so that the number of reindeer are limited by the winter feed, while much grass remains surplus and could be utilized by musk ox. The relatively restricted area of the musk ox to-day in Arctic Canada is solely due to the ease with which it is hunted. Now that it is protected by law, there is no reason why its range should not increase considerably.

The reindeer has been domesticated from early times in the Old World, even if we can not be sure that the reindeer of Stone Age man in Europe were tamed and not merely wild herds. The prosperity and very existence of most peoples of the Old World tundras from Lapland to Bering Strait to-day depend on the reindeer. Lapp, Zirian, Samoyede, Ostyak, Tungus, Chukchee, and Koryak are all reindeer breeders to a greater or less degree, and the reindeer provides them with meat, milk, clothing, and leather. They alone are the prosperous tribes, and their prosperity, as is the way of prosperity, causes them to look down on the hunting and fishing tribes such as the Yuchagir, Kamchadals, and some Samoyedes, who have a hard struggle to survive. Yet it should be noted that even among the Chukchee, who are the most successful reindeer breeders in Siberia, the reindeer is only partially domesticated, and the herds often run wild owing to the interbreeding with wild deer. The herds of the Koryaks also frequently revert to the wild state.

In the New World, including Greenland, the caribou has never been domesticated. The Eskimo are chiefly dependent on sea mammals and fish. Sea mammals yield a greater supply of oil, their only source of fuel and light, than caribou and musk ox. To the Eskimo land animals are a secondary consideration, valuable in the summer nomadism as offering a change of food and variety of occupation, but rarely now the staple of their existence. Even the Caribou Eskimo, inland dwellers to the west of Hudson Bay, have never tamed the reindeer, but exist by hunting the wild herds.

In his well-known efforts to dispel the prevalent misconception about the Arctic, V. Stefansson has drawn a glowing picture of the future of the Arctic prairies.[13] His statements have met with some

---

[12] The Canadian Government now offer £6 per pelt for wolves destroyed in the Northwest Territories. The skins find a ready market. In 1926 about a thousand wolves were thus accounted for.

[13] V. Stefansson, The Northward Course of Empire (1922); The Friendly Arctic (1921); Polar Pastures, The Forum, January, 1926, and other articles.

criticism, not invariably by men who know the Arctic. It may be well to examine his arguments in some detail, since this matter touches the future of the Arctic and its possible contribution to the material welfare of man.

Experiments in reindeer breeding in Alaska were begun in 1891 with the introduction of a small herd of 16 deer from Siberia. Next year 167 more were introduced. This was an attempt by the United States Government to give a new means of livelihood to the Alaskan Eskimo, who were in dire straits because game was exhausted. The experiment was entirely successful. The herds have been doubling themselves every three years, and the 1,280 deer introduced before 1902 have now increased to about 500,000. The United States Department of Agriculture calculate that the grazing grounds of Alaska can support over 3,000,000 reindeer at a low estimate. At present the deer are a small variety, but it is hoped to increase their size by interbreeding with wild caribou. This, however, must be done carefully lest the herds become unmanageable.

There can be no doubt of the success of the experiment in Alaska, and the forecast of an Alaskan production for the market, in less than 20 years, of over a million carcasses of reindeer a year is probably no exaggeration. This is the equivalent of nearly 3,000,000 sheep, and so would be no small accession to the meat resources of the United States.

It has been suggested that the Alaskan success shows what can be done in Arctic Canada, the barren lands and islands, and possibly also in parts of Greenland. Undoubtedly there are wide grazing grounds that are now practically unoccupied, but it is easy to exaggerate their potentiality. Estimates of productivity based on the number of species of plants here and there or per square yard have little value. Many of the plants are of no use to grazing animals and others are rare. It must never be forgotten that most Arctic plants grow slowly and have poor means of reproduction, so that Arctic prairies can easily suffer from overgrazing. One reason for the wandering of the caribou and musk ox is their liability to exhaust any but the richest grazing grounds to such an extent that a year or two, or even more, are required for their recovery.

Siberian reindeer in a wild state commonly migrate southward to the forest edge in winter, and even on the rich pastures of Lapland nomadism is essential. The Lapps know well that the sites of the winter villages must be frequently changed in order to insure enough lichen for the herds. Intensive pasturage on confined areas is impossible.

Six years ago the Hudson's Bay Co. acquired from the Canadian Government a lease of 100,000 square miles of tundra in southern Baffin Island and imported 500 reindeer from Norway to Amadjuak

on Hudson Strait. All the deer perished. Yet the failure of the experiment must not be used as an argument against the possibility of reindeer breeding in Arctic Canada. Siberian reindeer, for there are many varieties of the reindeer, would probably have suited the conditions better than the tamer and richer-feeding Norwegian variety; and, furthermore, Baffin Island, as its small ice fields bear witness, has a greater precipitation than most reindeer lands and a humid climate seldom suits reindeer. The failure to acclimatize reindeer in the Orkneys and the Scottish highlands many years ago was attributed, no doubt rightly, to the dampness of the climate, for the food supply was entirely adequate. Lastly, the wolves of Baffin Island made serious inroads on the new flocks quite unprepared to defend themselves from this unknown enemy. The wolf is a far more serious enemy than man to the reindeer and more effective in reducing numbers.

There is no reason to suppose that the domestication of reindeer, starting with Siberian stock and gradually introducing the American caribou, will be anything but successful in most parts of the Canadian tundra, in the rich pasture lands of western Greenland, and the more restricted areas of Spitsbergen. All these regions have supported vast numbers of reindeer in the past and should do so again if excessive hunting is curbed, wise game laws instituted, and the wolf exterminated, as Canada is endeavoring to do. Already the killing of reindeer in Spitsbergen is totally prohibited until 1934, the first enactment of Norway's rule in her Arctic possession.[14]

Alaska is said to have pasturage for 4,000,000 reindeer. Basing his estimate on this figure, Stefansson calculates that the Arctic tundras as a whole are capable of supporting about 100,000,000 reindeer and perhaps five times as many musk ox. This is probably an over-sanguine estimate, for it must be remembered that the Alaskan herds are mainly in the more fertile valleys of the south and southwest, which have few, if any, equals in fertility in the tundras farther north; but even if we reduce the numbers considerably, say by as much as 50 per cent, there remains a possible food production from the waste Arctic lands equivalent to some 1,000,000,000 sheep, or more than ten times the total number of sheep that Australia now supports.

This would, of course, take many years to accomplish, and naturally will not occur until the temperate lands of the world are more fully occupied than at present. But gradually, as world population multiplies and food production has to be increased, the lands that are not fit for cereal growth will command attention by their

---

[14] Norwegian proposals for game laws are published in Naturfredning i Norge, Årsberetning, 1926 (Oslo, 1926). See also Scottish Geog. Mag., May, 1926.

possibilities for pasturage. It is a geographical axiom that the herder must always give way to the tiller of the soil with his more intensive occupation. With the extension of dry farming there seems little likelihood of any considerable areas of temperate lands in the long run being left to pastoral pursuits. But the Arctic tundras are entirely unsuited for agriculture by unfitness of soil and shortness of summer for ripening the grain. Their advantage as pasture land is that the farmer can never displace the herdsman. As the world's supply of beef decreases, the supply of venison and musk-ox flesh will come more into demand.

A further important aspect of Arctic pasturage has been suggested in the supply of leather and wool. The musk-ox wool has been shown to have the qualities of merino and to be softer than cashmere, but it is unlikely that it will be possible to shear flocks that have to resist the rigors of a long Arctic winter or the pestilential irritation of the mosquito in summer.

The reindeer industry in Alaska is largely in the hands of Eskimo. It was started to maintain them, and 70 per cent of the flocks now belong to Eskimo. In Siberia, where the reindeer are for native use only, there being no export of meat as from Alaska, all the herds are owned and managed by natives. In Arctic Canada when the industry grows no doubt Eskimo and Indians will be largely employed to tend the flocks, but the slaughter of the beasts, the preparation of the meat and its export, as well as the transport arrangements will no doubt be in the hands of Americans, Canadians, and Europeans. Eskimo and white will meet even more than they do to-day.

The experience of the past in every quarter of the globe of the fate of hunting peoples in contact with more highly organized races gives room for legitimate doubt as to the ultimate survival, still less the increase, of the different peoples of the tundra. The clash of widely divergent cultures, to say nothing of the introduction of new diseases, almost invariably has meant the extinction of the more primitive people.

The same will probably occur in the Arctic. The latest reports from the Northwest Territories of Canada do not hold out much hope for Eskimo survival. The Eskimo are depending more and more on the police and trading post for supplies and help. Only the remoter tribes seem to preserve their strength and independence. The Hudson's Bay Co. and the Canadian Government, through the mounted police, are doing all they can for the Eskimo in sheltering him from the evil effects of civilization. Yet the fact is admitted by the police themselves that the sturdiest and most attractive Eskimo are those who are not in contact with outposts of the white man's

civilization.[15] Siberian natives in their greater isolation will no doubt last longer, but they also show signs of failing.

Up to the present the tide of human migration has flowed and ebbed on Arctic shores and has been mainly a seasonal movement, marked even in the permanent residents by a great degree of nomadism. But eventually the tide of white settlement will definitely set northward, even to the Arctic seas, and in its flood destroy the present inhabitants.

It is no more presumptuous to forecast a scattered population of reindeer and musk-ox farmers in the "barren lands" of Arctic Canada, the tundras of Siberia, and even in Greenland and Spitsbergen too, a hundred years hence than it was a hundred years ago to suggest sheep farmers in the plains of Australia or wheat fields in the Peace Valley of Canada. Every land beyond the frontiers of settlement has been a "never-never land" to unadventurous and unimaginative folk living in sheltered homes. But in most cases the prediction has been falsified.

Prejudice and antipathy, which loom so strong at present, can be ignored. When the Arctic calls for population and offers inducement in the form of material gain, all difficulties of that kind will vanish, just as the old-time horror of the Tropics disappeared as knowledge grew and prospects of gain loomed through the heat. The only question that remains unanswered is the adaptability of peoples of European descent to life in the Arctic climate. At present there is little evidence on which to base satisfactory conclusions, for nearly all migration in historic times has been either within the temperate zone or from temperate to tropical. There are few instances of migrations from temperate to polar or even from warmer to cooler climates.

The problem is one of considerable importance in the future of human settlement for two reasons. First, because there is no real evidence that the white races are suited for the Tropics—that is to say, for permanent racial transference as apart from visits. All the evidence that is conclusive points the other way and suggests that only by a slow process of natural selection can the white races ever find a sure footing in the Tropics. Long before that is achieved the colored races will have effectively occupied the warm lands.[16] This means that the white races must turn, as in effect they have been turning for several centuries, poleward in their search for new homes. Secondly, the possibility of polar settle-

---

[15] See Report of the Royal Canadian Mounted Police, 1926, and K. Rasmussen, Across Arctic America (1927).

[16] From this statement it does not, of course, follow that all regions within the Tropics are necessarily uncolonizable by whites, since altitude may in certain places compensate for the ill effects of a tropical climate. Nor does it follow that a few exceptional families may not now and then persist in the Tropics for a generation or two, though such instances generally involve the introduction of fresh blood.

ments affects, as I have tried to show, the future food production of vast areas which at present enter little into the economic life of the crowded populations of food-importing communities.

There are plenty of isolated cases to illustrate the healthiness of polar climates and how a man can thrive in the Arctic for a year or several years. But it is unsafe to found faith in polar colonization on such cases. First, they are almost entirely cases of men, and secondly of men in the prime of youth and of strong physique and mentality at the outset. Witness the trappers of the Hudson's Bay Co., the fur traders of Siberia, or the adventurers in the Klondyke and Yukon gold fields. It has even been argued that because a negro accompanied Peary to the pole there is no reason why peoples of the Tropics should not colonize the Arctic!

Successful colonization entails not merely the maintenance of health and vigor during a shorter or longer stay in the new environment; it demands that race transference can take place and that the transferred population can thrive with undiminished fertility from generation to generation without the infusion of new blood from the mother country. From this point of view the health and energy of women and children is the important consideration.

The Danes in Greenland are the nearest modern approach to this state of affairs, but though the Danish families thrive during their stay in the north they do not regard Greenland as a permanent home; they are exiles counting the years until they can return to Denmark. At certain of the large mining camps in Spitsbergen there are Norwegian families of several years' uninterrupted residence with bright, healthy children born and reared in the far north.

There are, unfortunately, no data bearing on climatic energy in polar regions such as E. Huntington has collected for the United States and some other countries. But if his conclusions are true, that a low mean daily temperature is more conducive to high mental energy than a high or even moderate one, then we can be sure that the Arctic colonists will not at least suffer intellectual degeneration. On the other hand, those of us who have experienced the extraordinary physical energy which is one of the joys of life in polar climates must be a little skeptical of Huntington's further conclusion that a mean daily temperature of about 64° is the optimum for physical activity. That figure would appear to be too high, but of course it represents a value that is extraordinarily difficult to measure.

The only example of real Arctic colonization that exists is that of the old Norse colonies in southwestern Greenland founded in the tenth century. At their height the two colonies must have contained between 2,000 and 3,000 people, men, women, and children

scattered in about 280 farms, where they kept cattle, goats, sheep, and horses, perhaps raised a few poor crops of little account, and hunted bears, reindeer, and seals. There is no need to recall the history of these settlements, how trade with Europe gradually ceased, and how the Norsemen had entirely disappeared when late in the sixteenth century communications with Greenland were reopened.

Recent Danish researches at Herjolfsnes, near Cape Farewell, have discredited the old belief that the colonies disappeared either by Eskimo extermination or by fusion with the Eskimo races.[17] It now seems clear, at least as regards Oesterbygd, that the Norse race maintained its racial purity and did not "go native." The general reluctance of the Nordic races to mix with widely divergent stock was as noticeable then as it has been in later centuries. Examination of skeletons in the churchyard of Herjolfsnes reveals the interesting facts that while clothes and ornaments, in graves of the fifteenth century, show little trace of Eskimo influence, the skeletons all show signs of rickets or other malformations and stunted growth, but no sign of racial mixture with the Eskimo. There is also a very high proportion of remains of infants and young people. Evidently, therefore, the Norse colonies, at least Oesterbygd, perished by exhaustion. Even if the climate were changing for the worse during the existence of these colonies—and such a change is by no means proved—there is no reason to suppose that the habitual meat diet failed. The cessation of communications with Europe can not have affected the diet of the colonists to any great extent. The King's Mirror, describing conditions when the colonies were prosperous, notes that most of the settlers did not know what bread was. And what else could they get from Europe to vary their meat diet?

The conclusion is, therefore, that the Norse colonists in Greenland died out for want of new blood, or, in other words, that they were not acclimatized to their Arctic home. From this it might be argued that even the Nordics can never colonize the Arctic. Certainly no other race from temperate climates is likely to try, since the Nordics alone show that distaste for gregariousness and that capacity for enduring solitude which are essential qualities for the task. We may even grant them a greater measure of physical enterprise and love of wandering than other people.

The Greenland experiment is not, however, a sure criterion of Nordic unsuitability for the Arctic. The pastoral settlement, which is suggested, will be a slow colonization in which natural selection

[17] See papers by P. Nörlund, F. C. C. Hansen, and F. Jónsson in Meddelelser om Grönland, LXVII (1924), and by D. Brunn, ditto, LVII (1918).

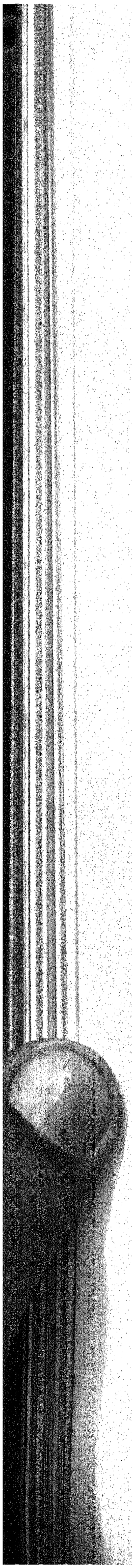
will have some say. Those suited will remain; others will move away or perish. But the colonists will not be cut off from the world; they will be in close touch with it. New blood will continually flow in their veins, so that the unchecked course of natural selection which operated in the old isolated Norse colonies and killed out the more nervous and imaginative type, a type that is least adapted to the Arctic, will not have free play. There is no reason why the race should become impoverished by the elimination of its most progressive element. Even though a diet solely of meat has proved wholesome enough in the case of Eskimo and some explorers, it will not be necessary for the Arctic colonists to subsist on it entirely; transport facilities will bring every variety of food to their doors. If the Norsemen suffered from insufficiency of certain ingredients in their diet, a similar fate will not be the lot of the colonists of the future. If they died out by lack of new blood and continual inbreeding, the Arctic settlers of the future will be able to avoid that disaster.

Such is the legitimate forecast, as I see it, of the outer rim of the Arctic of the future with its prosperous, though scattered, colonists of pastoral interests and its fur farms here and there supplying high-priced Arctic furs in limited numbers. But the settlement must wait until the pressure of population on the world's resources is even greater than it is to-day. The remoter parts, those without rich tundra and the ice-covered seas and lands must remain deserts visited only by roving hunters and occasional explorers. In short, I see a shrinking of the Arctic wildernesses, but never their disappearance. I can not take as glowing a view of Arctic settlement as Stefansson can or visualize the same attraction to population which he forecasts, and I am sceptical of the value of Arctic lands as stations on the air routes of the future. But even if he has overstated his case, his long-sighted views have done something to dispel current misconceptions and reduce the area of polar wastes.

Of the possibilities of Arctic mining, little need be said. The subject is not purely a geographical one. Where minerals of value occur they will sooner or later be mined, like the cryolite of Greenland, the copper of Arctic Canada, the coal and gypsum of Spitsbergen. Geographical considerations undoubtedly affect the issue, but in the main it is an economic problem. Difficulties of climate can nearly always be overcome, and transport can generally be arranged if the mineral will pay the cost. As coal increases in price, as it promises to do, the Spitsbergen coal mines will pay well, and if gypsum finds new uses and higher values the vast deposits of Spitsbergen will be mined on a great scale. Similar considerations apply to Arctic copper. But the Arctic lands as a whole, as far as we know, are not rich in mineral wealth. The only one that will eventually have a large mining popu-

lation is Spitsbergen, and there manufactures may develop in relation to the gypsum and metallic ores.

The Antarctic has no human problems comparable with those of the Arctic. It is true that whaling has recently invaded the Antarctic, with the vessels in the Ross Sea, not to mention the sub-Antarctic whaling in South Georgian and Falkland waters. But this can be little more than a passing phase. Already some species of whales show signs of depletion of numbers, and unless whaling is so rigorously shackled by regulations as to make it of little profit compared with the risk it entails the industry must kill itself in a few years' time. For the rest there is nothing of value in commerce in the Antarctic—certainly nothing that it can possibly pay to exploit. The stories of future Antarctic coal mines can be dismissed as a dream without any solid foundation. It is fortunate. And those of us who care for the wild waste spaces of the world are glad to think of the Antarctic as free from invasion by our modern civilization with its insistence on hurry and noise. We are glad to remember the lonely places of the world and their matchless beauty, content to know that to others they will bring the same fascination they did to us in years gone by.



BIRDS OF THE PAST IN NORTH AMERICA [1]

By ALEXANDER WETMORE

[With 11 plates]

When one considers that the number of forms of living birds known at the present time is approximately 25,000, the fossil species that have been discovered are remarkably few. The most recent synopsis of the fossil birds of the world, that of Koloman Lambrecht, published in 1921, includes only 700 species, part of them of doubtful identity. The list has been increased only slightly in the seven years that have passed since this publication. At the present date (October, 1928) there have been described 155 species known only as fossils from that part of continental North America which lies north of Mexico (but including the peninsula of Lower California), this being the area covered by the American Ornithologists' Union in its official Check-List. To complete the roster of fossil forms for this region we must add 108 species now living whose bones are found in deposits of Pleistocene age, so that the list includes at the date just mentioned 263 names. The total is less than that for any other group of vertebrates except the amphibia for this region. The fossil reptiles, according to data supplied by Dr. O. P. Hay, now include 1,011, or nearly four times the number of birds, while the amphibians (without reference to supposed members of this group named from tracks alone) reach a total of 156.

That comparatively few students have taken up serious work on our fossil birds may be due to three factors: First, the small numbers in which fossil bird bones ordinarily occur; second, the incompleteness of the specimens in most cases; and third, the lack in most museums of skeletal material of modern birds for comparative use.

It is true that there have been occasional deposits in Pleistocene beds in North America where bones of birds have been found in great abundance, as at Fossil Lake in Oregon, and in the pitch deposits at Rancho La Brea in California, but these are exceptional both in number of individuals and in range of species represented. Ordi-

[1] Presidential address delivered before the Washington Academy of Sciences, Jan. 10, 1928. Reprinted, with change of title and some additions and changes, from the Journal of the Washington Academy of Sciences, vol. 18, No. 6, Mar. 19, 1928, pp. 145–158.

narily the careful collector of vertebrate fossils finds no bird remains whatever, or at most recovers only a few fragments in the course of a season's explorations in the field. Most of those obtained are secured incidentally in other excavations, the majority of bird bones being small and easily overlooked, or of such form as to offer little promise, so that when only partially exposed they may be disregarded by the searcher for striking specimens. In a few deposits fossilized feathers have been found (see pl. 9) and very rarely fossilized eggs (see pl. 2) are encountered but such finds are unusual and in most cases the specimens are in a highly fragmentary condition.

Bird remains in the fossil beds below the Pleistocene are characteristically fragmentary or broken. Leg and wing bones are those most usually encountered, with occasional parts of vertebrae, pelves, sterna, or ribs. Seldom are more than the merest fragments of skulls secured, and on relatively few occasions have complete skeletons been found (see pl. 1).

Birds as individuals exist in enormous numbers, and as there is naturally a constant mortality among them it might be expected that their fossil remains would be abundant. There is no reason to suppose that birds were less common during the Tertiary than now; in fact there is ground to believe that they may have been more numerous prior to the Recent Period than in the present century. Our present race of civilized man was not then developed to trouble them; and there is no question but that the rising dominance of man in the last hundred years has had far-reaching effect in reducing the total number of birds, both by man's personal activity in hunting, and by the changes in ecological conditions that have attended his agricultural and commercial developments. Many of our existing species of birds are now able to maintain their living status only through restrictions arranged for their benefit by those far-sighted persons who realize the necessity for conservation in connection with our remaining wild creatures.

It would seem then that in previous geologic ages there may have been more birds present in North America than exist to-day. That few individuals seem to have been preserved as fossils is apparently due to the fact that the bones of birds are so light that they are easily destroyed. Most of the limb bones in birds have a hollow center, with comparatively thin walls of dense, rather brittle structure, and when subjected to undue pressure are crushed or broken. Most birds die through capture by some predator, or if overtaken by disease are eaten promptly by some scavenger. As the majority are of small or medium size they are often entirely consumed, and their bones comminuted or destroyed by the strong digestion of the creature that has found or captured them.

That this destruction is the usual course when birds die will be attested by field naturalists when they reflect upon the hundreds and thousands of living birds that are seen and the relatively small number of instances in which remains of dead birds are encountered. Armies of predatory or scavenger creatures, many of them unnoticed by the average individual, destroy the carcasses immediately upon death.

The bones that in past ages through fortuitous chance have escaped this destruction are frequently of little moment to the paleontologist. Bones of the toes, ends of the ulna, broken bits of the coracoid, or fragments and slivers from the shafts of long bones, all of which are common as fossils, ordinarily offer no distinctive characters, and, in the main, should be disregarded by the careful student. Unfortunately through the enthusiasm of early workers in the science these have served frequently as the basis of description for names that are now stumbling blocks in modern paleontological studies.

In work in the field I have been interested in observing the skeletal remains of birds, and have found that chance to-day seems to favor the preservation of exactly the same type of fragments as those found among Tertiary fossils. The body of a duck or a heron is eaten by some coyote or vulture which tears out the breast and the viscera, destroying part of the sternum, breaks the skull to obtain the brain, and mangles the wings and thighs. The remaining portions dry somewhat, and the flesh is removed either fresh or dried by the work of insects. The broken skeleton that remains is light, and unless anchored by vegetation, blows about with the wind or is swept by running water. Bit by bit it falls apart and is scattered over the space of several square feet. Occasional bones are buried, usually in such a way that they may be subject to decay, or, less often, where they may be preserved. Even where vertebrate scavengers are not active, delicate portions and many of the more sturdy bones disappear.

Imperfect preservation is common where predatory enemies are absent. On the islets in the Hawaiian Bird Reservation thousands upon thousands of birds of moderate size live without interference from the usual enemies that prey upon birds in continental areas. It might be expected that here complete skeletons would be preserved in large quantity since there is the usual regular mortality among the assemblage. I found, however, that even here the carcasses disintegrated, while the thinner parts of skulls, sterna, and pelves, under the combined effect of sun, rain, and wind-blown sand, were corroded away, and the firmer bones were scattered by violent gales. On Laysan Island many found a resting place in the concentrated saline waters of a shallow, central lagoon, and here on investigation I found

a veritable cemetery of bird remains, mostly composed of the long bones that are characteristic of fossil deposits. These thousands of fragments were being steadily buried in the sands that blew in upon them, so that the lagoon at Laysan may be a possible source of fossil deposits for study in the remote future if then there still exist beings interested or capable in such research. The situation on Laysan suggests that similar conditions have operated on many oceanic islands, and that there is opportunity for discovery of extinct forms of life when these are found and properly exploited. Formation of such large deposits seems to occur only under exceptional circumstances, it being more usual for scattered fragments to be preserved.

The certain history of the class of birds as known in North America at the present time must be considered to begin with the Cretaceous period of geologic time. It is true that there is one species called *Laopteryx priscus*, described by Marsh from the Morrison formation in southern Wyoming, that in late years, without particular reason, has been listed in the same family with *Archaeopteryx* of the Old World. As there is, however, some doubt that *Laopteryx* is actually avian, its systematic position must be considered vague until it has been more carefully studied. Another fragment, described by Emmons in 1857 as *Palaeonornis struthionoides*, from what are considered possibly Triassic beds in North Carolina, is also so doubtfully avian as not to merit consideration at this time.

The first fragment of a fossil bird from this continent of which we have record, a part of a tibia, was secured by S. W. Conrad in the extensive marl beds near Arneytown, N. J. This was mentioned in 1834 by Doctor Morton in his "Synopsis of the Organic Remains of the Cretaceous in the United States," as a species of *Scolopax*, but was not actually described until 1870 when Marsh bestowed upon it the name *Palaeotringa vetus*. It is believed to be a primitive member of the shore-bird group.

The birds of greatest interest found in the Cretaceous period are species known to have teeth, first described from specimens found by Marsh, and parties working under his direction in the Niobrara beds of western Kansas. Of prime importance among these are the members of the family Hesperornithidae, in which there are at present recognized five species. Several practically complete skeletons have been discovered, so that in spite of their antiquity these fossil forms are fairly well known (see pls. 3 and 4). The species of *Hesperornis* were diving birds with greatly elongated bodies, strong legs, paddle-like feet, and long necks, with the jaws set with sharply pointed teeth placed in continuous grooves. The vertebrae were saddle-shaped like those of modern birds. The lower jaw had teeth set along the entire length, but in the upper jaw, teeth were placed

on the maxilla alone, the premaxilla being smooth, so that apparently even at this remote date there began a tendency to tooth reduction which has resulted in the toothless jaws found in modern birds. The various species of *Hesperornis* lived in the shallow seas that covered parts of the interior of our country in the Cretaceous, and from their form seem to have fed on fish which they captured by diving. They were so adapted for aquatic life that they had entirely lost the power of flight. In fact the wing is known from the humerus alone which is reduced to a slender, curved stylus, the head of which has so slight an articulation on the scapular arch that it is evident that it had little function. It is possible that the remaining wing elements were represented by rudimentary bones but these have not been identified, and if present at all they must have been very small.

Early constructions of the skeleton represented *Hesperornis* in an upright attitude, but on more careful examination of the articular surfaces of the leg bones it was found that the legs projected at right angles from the body so that it is doubtful if the bird could stand on them at all. It appears that *Hesperornis* presented the most highly specialized developments for aquatic life of any bird yet known. It traveled through the water by propulsion of its tremendously powerful feet, which are of such form and have such size in relation to the remainder of the skeleton that it is probable that at need the bird could develop the speed and agility in turning found in the modern shark or porpoise. On land, if it ventured at any time on terra firma, the bird must have progressed like a hair seal, prostrate on the breast; it is possible that it built a nest of floating vegetation in the water like the modern grebes, and seldom if ever did more than flounder out on shore to rest in the sun. If its eggs were placed on shore, we must suppose that they were deposited near the water's edge like those of loons.

Marsh, deceived by the flat sternum, on which there is no keel for the attachment of flight muscles, characterized *Hesperornis* as "a carnivorous, swimming ostrich," while later authors have considered it as perhaps ancestral to the modern grebes and loons. In point of fact *Hesperornis* is so highly specialized that it is doubtful that it may be considered ancestral to any modern form other than that it represents a type of bird that lived at an earlier age. Resemblances to *Hesperornis* seen in modern species appear to be merely those characterizing birds as a group, or are the preservation in a few of ancient characters which in the Cretaceous may have been developed in all forms of birds.

The second type of toothed bird, described from the Cretaceous by Marsh, is *Ichthyornis*, a genus in which seven species are at present recognized. *Ichthyornis victor* (see pl. 5) and *I. dispar*,

the two that are best known, in body were about as large as a domestic pigeon. The neck was long, and the head was large and strong, with long jaws implanted with many small, sharply pointed, recurved teeth set in sockets. The wings were large, long and strong, the sternum heavily keeled, and the legs and feet comparatively weak. The biconcave vertebrae, which have the form found in fish and some amphibians, and are unlike those of any other bird, were the most peculiar feature of the group. *Ichthyornis* was entirely different from *Hesperornis* in that it was preeminently developed for flying. That it flew by feathers, and not by means of a skin membrane as do bats, is shown by tubercles for the attachment of secondary feathers on the ulna, and the ankylosis of the metacarpal elements into one bone to form a firm support for the primaries, the long wing feathers on the outer part of the wing. As a flying form it is apparently nearer the central stem from which have come our modern birds than is *Hesperornis*. *Ichthyornis*, however, shows primitive tendencies in that it still carried the amphicoelous or biconcave type of vertebral articulation, so that it combines the ancient with the new, as a grandmother may don the dress of a modern maiden. *Ichthyornis* has been postulated as ancestral to modern terns or skimmers, but here again I believe that resemblance is merely convergent, due to the restriction placed by method in flight on the evolution of bodily form in birds. It is my belief that birds of the Cretaceous had as varied form as those of modern times, and that there is no direct linear connection between the few fossils of this time yet known and existing groups.

Certain other Cretaceous fossils (*Apatornis celer* and *Baptornis advenus*) from the Niobrara beds are placed among the toothed birds. From the evidence of *Hesperornis* and *Ichthyornis*, the only forms in which the jaws have been found, it would appear that teeth may be a character to be expected in all ornithic forms of the Cretaceous, and that we should not, therefore, put any Cretaceous bird in a modern family unless its skeleton is completely known.

There are described from New Jersey three species of a genus known as *Palaeotringa* that are currently located in the modern family Scolopacidae which contains the snipes, and three more of the genus *Telmatornis* that are allocated in the family Rallidae among the rails. Another, *Laornis edvardsianus*, is considered as an anserine bird of the family Anatidae that contains the ducks, geese, and swans. These were supposed for many years to be Cretaceous forms, but recent studies indicate that the particular marl beds of New Jersey from which they come are not Cretaceous, but are in reality Eocene, so that the birds indicated must be transferred to the Tertiary.

With the beginning of the Tertiary period there is a sudden change in our known fossil avifauna. Toothed birds have disappeared and

the forms found are more like modern types, so that the greater number of the approximately 25 species of fossil birds that have been described from the Eocene of North America are now placed in modern families. It may be said that a number of these have been named from very inadequate material and that some, perhaps, may not be birds, as the bones from which they have been described are so fragmentary as to make it difficult to decide whether they belong in the Class Aves or elsewhere among the vertebrates. Others on further study may be found sufficiently peculiar to warrant their separation as distinct from living families.

Diatryma steini from the lower Eocene (Lower Wasatch) of Wyoming is one of the few fossil birds found that is represented by a nearly complete skeleton (see pls. 6 and 7). This great bird stood nearly 7 feet in height and was developed for a terrestrial life. It possessed strong legs, and a heavy head, with a great arched bill, and very small, almost aborted wings. Superficially it suggests the remarkable *Phororhacos* of Patagonia, and probably was similar in habit. It has been described fully by Matthew and Granger but has not been carefully studied, so that its exact affinities are not certainly known. It is placed at present near the cranes and rails, but does not seem to have very close affinity with either.

Another form that is known from a nearly complete skeleton is *Gallinuloides wyomingensis* from the middle Eocene (Green River) of Wyoming, a gallinaceous form, typical of a special family related to the curassows and guans, fowl-like birds that live among the branches of trees. *Minerva saurodosis* of the same age is apparently a primitive owl, while *Presbyornis* is a shore bird placed in a separate family from any of our modern species. It seems to have resembled an avocet but probably was more aquatic and swam more readily. *Nautilornis* was an auklike form that differs from modern auks in that it seems adapted for wading as well as for swimming. Other species that have been described from this age are so fragmentary as to be uncertain in character.

Bird remains from the Oligocene of North America are as yet few, so that to date only six species have been recorded. Two of these, a cormorant, and a supposed pheasant named by Shufeldt, are of uncertain status. The only important deposit of this age that has yielded much bird material to the present is one in Weld County, Colo., where collectors from the Colorado Museum of Natural History in Denver, in exhuming great series of such strange mammals as *Trigonias*, *Symborodon*, and *Archaeotherium*, have uncovered a few bones of birds. From these the writer has recently described four species representing peculiar genera not known in modern times. *Phasmagyps patritus* is a vulture related to the living black vulture but about one-half larger. *Palaeogyps prodromus*, in the same family

(see pl. 1), is more like the California condor but is only two-thirds as large. *Palaeocrex fax* is a large gallinule, apparently between two and three feet in height, and *Bathornis veredus* is a species of the shore-bird family of thick-knees or Œdicnemidae (see pl. 1). *Bathornis* was peculiar in possessing a hind toe which is missing in living representatives of the family. Further species of extinct birds from the Oligocene will be awaited with interest since in that age we may expect the earliest species that are at all closely similar to those living to-day.

The 23 birds certainly allocated to the Miocene include a considerable variety of forms. In Colorado, in the deposits known as the Florissant lake beds, famous for the insect and plant remains that they have produced during the past 50 years, there have been found remains of several birds. A plover has been described as *Charadrius sheppardianus*, while another species, a perching bird about as large as a cedar waxwing or bluebird, has been named *Palaeospiza bella* by J. A. Allen (see pl. 9). During a recent examination of the type of the latter species I have found that it is representative of a peculiar family to be known as the Palaeospizidae, which belongs near the base of the oscinine subfamily of the perching birds, immediately above the larks, or Alaudidae.

Another avian species from these same Florissant beds has had a curious history. In 1883 the paleobotanist Lesquereux proposed the name *Fontinalis pristina* for a specimen that he thought was a bit of a fossil moss. In 1916 Knowlton called attention to this species indicating that the fragment on which it was based was not a plant, but was in reality a bit of a feather. *Fontinalis* must, therefore, be transferred to the avian list where it is placed in the group of *incertae sedis* without much hope ever of ascertaining its proper relationships.

Among other Miocene fossils there have been found in the beds of diatomaceous earth at Lompoc, California, a number of birds from which Loye Miller has described six species, a shearwater, three gannets and boobies, an auklet, and a shore-bird. These occur as flattened impressions or silhouettes in beds of nearly pure diatomaceous material. The species thus far identified are mainly fish-eaters, and in part may have come to a shallow Miocene bay to feed on myriads of herrings whose remains abound in the same beds. The most abundant bird is *Puffinus diatomicus*, a shearwater allied to the living blackvented shearwater (see pl. 8). *Limosa vanrossemi* is a godwit much like the modern marbled godwit. *Sula willetti*, a booby somewhat like the living red-footed booby, is of interest in that it shows the same type of closed external nostril found in modern Sulidæ, indicating the great antiquity of this character. The bone in these Lompoc specimens has been so altered that on exposure to the air it crumbles and disappears, leaving only an impression that

in turn is evanescent as the material in which it is formed is soft and friable.

The Miocene of the Sheep Creek and Snake Creek beds of northwestern Nebraska under exploration by the American Museum of Natural History, Princeton University, the Carnegie Museum, and Mr. Harold Cook, has yielded a fair number of bones of birds from which I have described seven species, including a hawk, *Buteo typhoius*, related to the modern red-tail, two small eagles, *Geranoaëtus ales* and *G. contortus*, of a genus not found outside South America in a living state, and a kite, *Proictinia effera.* There is also a peculiar limpkin, *Aramornis longurio*, and a small paroquet, *Conuropsis fratercula*, allied to the modern Carolina paroquet but smaller. One may picture the area as a badlands section where hawks and eagles, with nests on the sides of cliffs, dropped the bones of their prey on the slopes below, to mingle with occasional bodies of the predatory birds that had brought them to the place.

The Pliocene, like the Oligocene, has fossil birds poorly represented as yet, as at present we know only 10 forms from within the limits of this age. The upper Snake Creek in Nebraska, which is placed in the lower Pliocene, has given us an eagle, and a species of chachalaca, *Ortalis phengites*, a tree-haunting, gallinaceous type of a group not found to-day north of the lower Rio Grande Valley. From these same deposits I have received the humerus of a crane that is seemingly identical with the existing sandhill crane, the first instance known of remains of a bird still living to be found below the Pleistocene. From beds ascribed to the Upper Pliocene in southern Arizona I have identified a small goose, *Branta minuscula*, a tree duck, *Dendrocygna eversa*, a sandpiper, *Micropalama hesternus*, and a dove, *Chloroenas micula.*

Though a part of the birds of the Miocene and Pliocene are peculiar many are identified in genera existing at the present time. It is my own belief that these two ages mark the period of evolution of our modern genera of birds and that there has come comparatively little change in generic type since. In my opinion evolution among birds during the Quaternary has been concerned principally with the development of those differences that characterize species and subspecies, differences which in some cases have been so pronounced that present usage, with its close perception of minutiae, concedes them as generic. When broad, comprehensive limits are given generic groups, however, these seemingly have had their origin in the latter part of the Tertiary.

It seems probable that the bird life of the Miocene and Pliocene was even more varied and wonderful than that of to-day, and that a larger number of species may have existed. We are told that climatic conditions in that time had not developed such sharply

marked zonal characteristics as in the Recent period, so that though the temperature was not oppressively warm it was modern and fairly uniform at points much farther north than under modern conditions. Forms that we consider now as subtropical, in the Miocene and Pliocene ranged north into northern Nebraska, and probably further. We are aware that the present number of species in tropical and subtropical sections of America is much greater than in the Temperate Zone. Ecuador for example, in the geographic limits at present granted to it, has approximately the same area as the State of California. The known bird life of Ecuador at the present time according to Chapman, numbers 1,508 forms, more than for the whole of North America north of Mexico, while that of California at the end of 1924 (the latest published revision of the list) included only 594 species and subspecies. By analogy we may suppose a rich and highly varied bird life for the Miocene and Pliocene periods in North America, a fauna that since has been in part exterminated, and in part restricted to more southern latitudes. Further research may be expected to increase considerably the list of fossil forms known from this section of geologic time.

With advance into the Pleistocene we come to an age in which the fossil avifauna becomes much better known through more numerous occurrence and greater abundance of specimens. Fifty-one extinct species have thus far been described from our Pleistocene beds, evidence of a rich avifauna. There are in addition 108 species of birds still existent whose remains have been identified in Pleistocene deposits, so that the entire group of this period includes 159 forms of birds, more than half our present list, and a considerable number when we consider the smaller figures yielded by our census in previous ages.

It may be remarked parenthetically that the more than 50 extinct species that have been described from the Pleistocene are definite indication of what has been said above of the probable abundance of birds at the close of the Pliocene, since these forms undoubtedly had their evolution prior to the Ice Age and were in existence at its beginning. From somewhat meager information I am inclined to regard the close of the Tertiary as the period of greatest diversity and abundance in bird life in the earth's history so far as North America is concerned, and to believe that with the rigors of environment incident to the opening of the Pleistocene, and the even more unfavorable conditions of the historic part of the recent period occasioned by the increase of man over the earth, there has been steady reduction and extermination among birds, a process that will continue in spite of protective regulation until most of the peculiar forms have disappeared and only the more adaptable ones remain.

To return to our Pleistocene avifauna, we find several deposits that have yielded abundant bird remains. The earliest known of these important beds was that of Fossil or Christmas Lake, in the arid section of Oregon, where deposits containing hundreds of bones of birds have been explored. These, studied first by Shufeldt and later by Miller, have given a varied list of birds, mainly aquatic, of which a number have been described as species distinct from those existing to-day, and many have been identified as identical with living forms. Dr. O. P. Hay considers the age as first interglacial. Of the more than 20 peculiar species only one, *Palaeotetrix gillii*, is now held to be generically distinct from living birds. The flamingo, *Phoenicopterus copei*, is the most unusual species in the assemblage, as any of the other genera might be expected in this area to-day. It may be remarked that the flamingo is no criterion for particularly warm climate at the time mentioned, since a somewhat similar species of flamingo now ranges and nests in South America through Patagonia where the summer weather is often cold and inclement.

The deposits of bird bones from this Oregon locality are found in an old lake bed that from modern conditions might be supposed to be similar to the small alkaline lakes now common in this area. If this is true it is possible that the great abundance of bird remains is indicative of a condition in the Pleistocene similar to one that has destroyed hundreds of thousands of waterfowl in the western part of the United States in recent years. The malady to which I allude, the so-called "duck sickness," has been especially prevalent in the past 20 years in the deltas of streams flowing into Great Salt Lake in Utah, but is known in alkaline lakes in a number of other sections, including the Malheur region of Oregon. Briefly, it appears that birds, principally ducks and other aquatic species, become affected by excessive concentrations of alkalis in the waters in which they feed, and, unless they can have immediate access to fresh water, they become paralyzed and die. Aquatic birds of various kinds have been affected and the number of individuals known to have been thus killed in the last 20 years has been tremendous, running literally into the millions. The possibility of the accumulation of extensive deposits of bones of birds that may be preserved as fossils under these conditions is easily evident.

The most famous deposit of Pleistocene vertebrate remains in the New World is that of Rancho La Brea on the Californian coastal plain only a few miles from the business center of the city of Los Angeles. Here outpourings of asphalt from the depths of the earth have been exposed in such a way that they have served to entrap animals which were held in sticky embrace until death came to them, and then, when decay had released their skeletons, to entomb the bones in a bed of tar where many have been preserved in perfect condition.

The manner in which this pitch trap operated is seen in minor deposits that form to-day, as it is not unusual to find small mammals or birds held fast in viscous asphalt seeps. Under careful exploration the beds at Rancho La Brea have yielded bones to an aggregate of many, many thousands, and have included very large numbers of remains of birds. To the present time Loye Miller has published identification of nearly 60 species, and there are unquestionably others to come as the smaller forms, the passeriform or perching birds in particular, have not yet been carefully studied. Two-fifths of the forms from these deposits are extinct. Such scavengers as vultures, which would be attracted to the bodies of dead animals, are represented in abundance, and include several extinct genera. Among these the most curious is the great *Teratornis merriami*, which is known from almost the complete skeleton, and represents the largest of flying birds, exceeding in wing spread the modern condors (see pls. 10 and 11). Another species of great abundance was a gallinaceous bird, *Parapavo californicus*, supposed at one time to be a peacock, but now admitted as a species of turkey. The age of these deposits is placed by Hay as first interglacial.

Asphalt deposits of similar kind have been found recently near McKittrick, and near Carpinteria, Calif., giving additional information on the distribution of the avifauna of California in the Pleistocene, which, in its abundance of vultures and large hawks and entire lack of gulls, offers a decided contrast to that of Oregon.

Recent explorations in Florida, near Vero and Melbourne, in what are supposed to be Pleistocene beds, have yielded remains of birds in which are found the great stork known as the jabiru, and various other species. Recently a valuable collection gathered by Mr. W. W. Holmes near the west coast has come into my hands for study, and on preliminary examination is found to contain a considerable variety of species. Most remarkable is a broken metatarsal of a male turkey with a trifid spur core that may represent an unknown species. Multiple spurs are known among certain pheasants, but have not been recorded among the gallinaceous birds of North America. The Holmes collection when fully identified will add considerably to knowledge of the ancient Floridian avifauna as it embraces the most comprehensive series of species of birds that has been found fossil in the eastern United States.

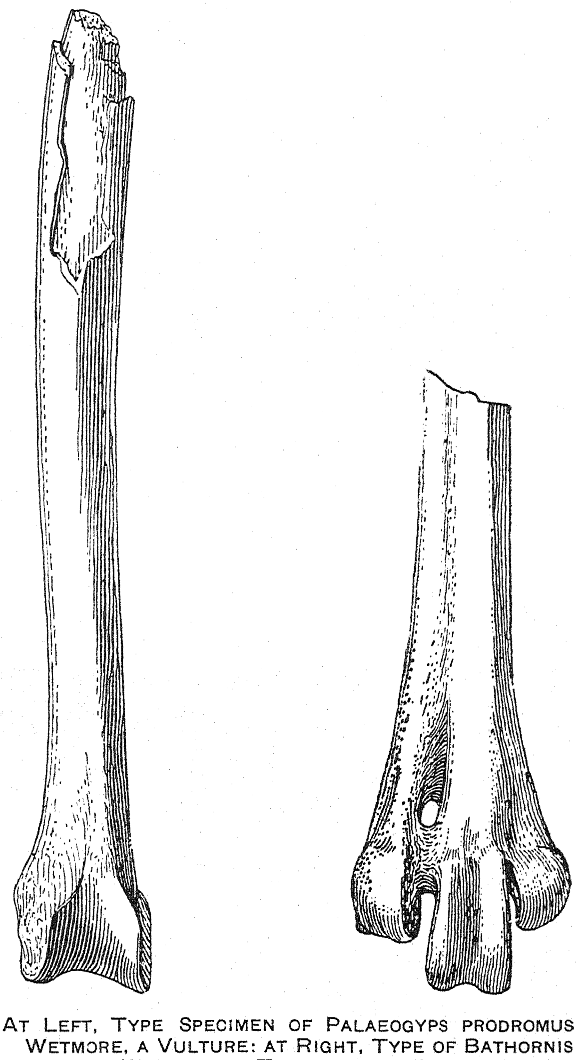
Cave deposits that have been explored in California, Pennsylvania, and Maryland, have contained remains of Pleistocene birds, that need not be described in detail except to remark that caverns offer a fertile field for investigation.

In closing it may be said that the discovery of additional forms in the Cretaceous is uncertain but that any obtained will be important. At the present time only two types are well known from this

period, one of diver form, and the other of flying habit that apparently fed on the wing over water. These are both so specialized that we may expect that other toothed birds existed though their possible presence is now indefinitely indicated by fragments of a few species of uncertain status. The Tertiary should give many more species than now known, particularly in its Miocene and Pliocene beds, and finally from the Pleistocene we may expect many forms in addition to those already discovered. From cavern and other deposits we may hope for more extinct species related to modern birds, some peculiar and some with relatives living to-day in South America.

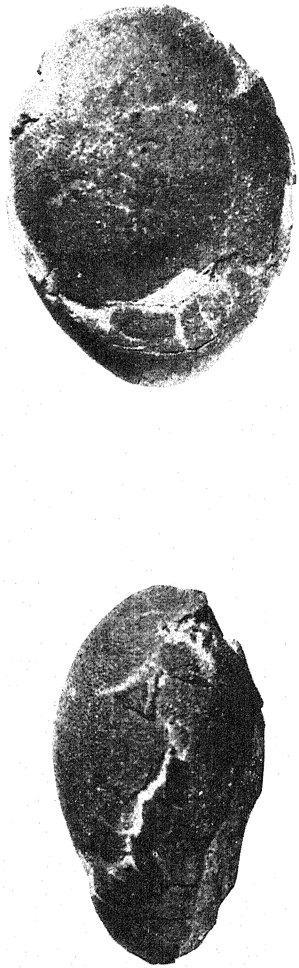
It has been already intimated that the number of extinct species of birds now known from North America is far less than is to be expected. As the forms described by earlier students are passed under review it is evident that much remains to be done to decide their proper status. Many have been named from such insufficient material that their systematic position is doubtful, while there are a few in which the type material is a composite of fragments that may contain remains from two or more families, so that selection must be made to properly apply the name. Some that have been called birds probably are not avian and eventually will be rejected from our list. Progress is being made steadily in these matters, and yearly the condition improves, so that our uncertainties become fewer and fewer. Such glimpses as our few fossils give us of the life of the past are fascinating and promise high return for the most painstaking study. At the present rate with which new material comes to hand we may possibly expect to see our knowledge of palaeornithology in North America doubled in the next 20 years.

24034—29——26



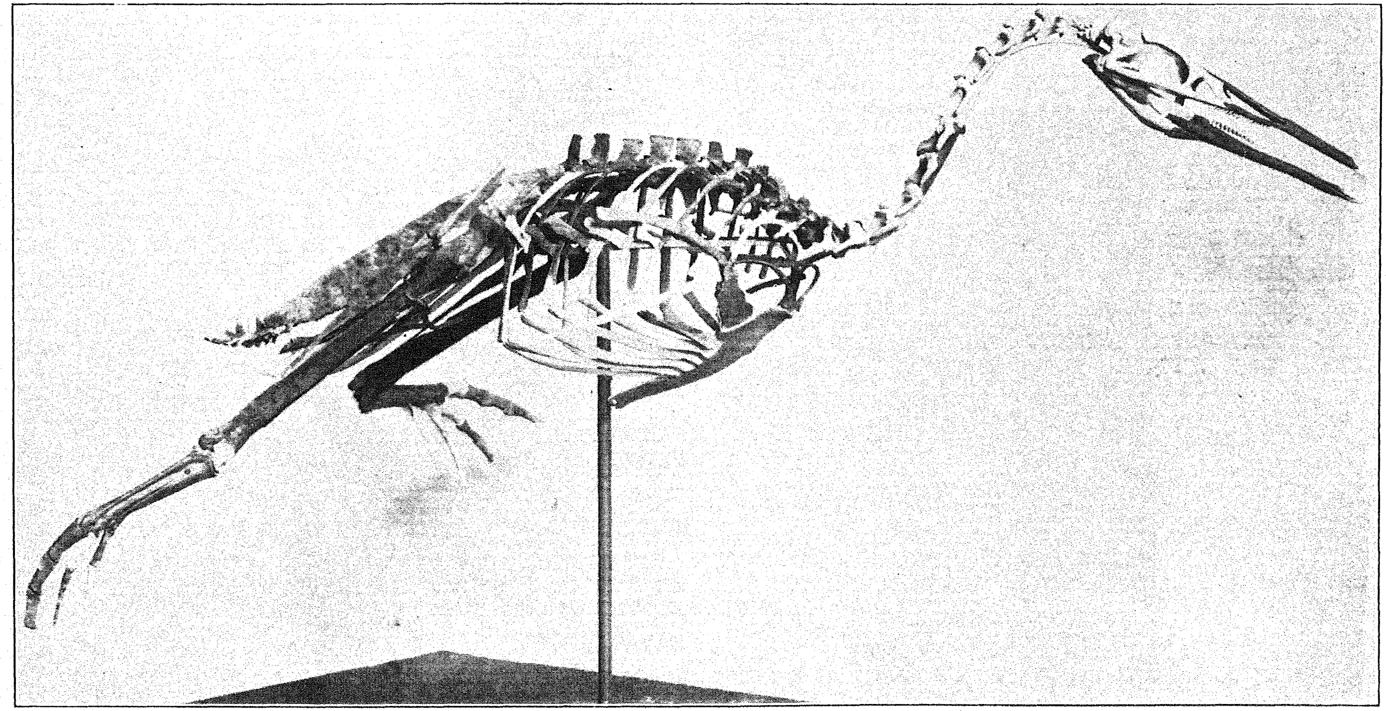
AT LEFT, TYPE SPECIMEN OF PALAEOGYPS PRODROMUS WETMORE, A VULTURE: AT RIGHT, TYPE OF BATHORNIS VEREDUS WETMORE, A THICK-KNEE. BOTH FROM THE OLIGOCENE OF COLORADO

These bones show the characteristic fragmentary preservation of fossil bird bones. (From original description published by the Colorado Museum of Natural History)



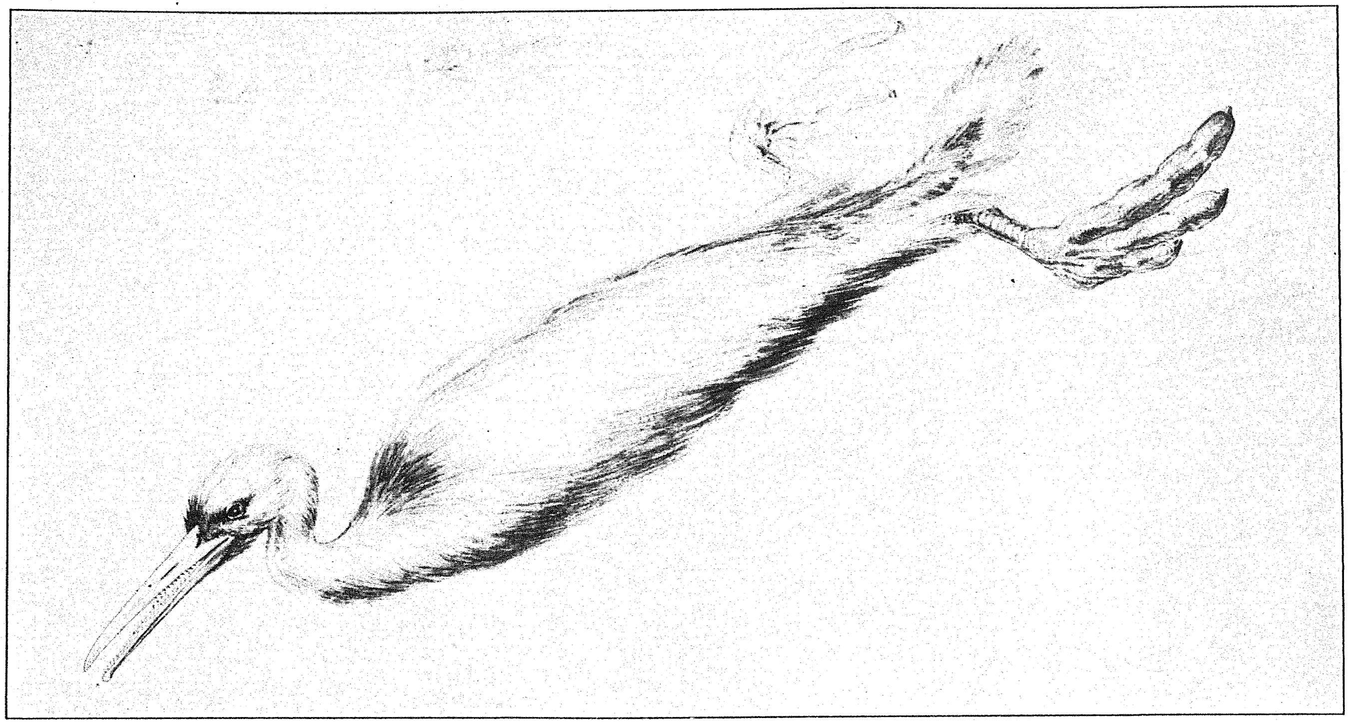
TWO VIEWS OF A FOSSILIZED BIRD'S EGG, FROM THE OLIGOCENE OF SOUTH DAKOTA

From a specimen in the U. S. National Museum. Natural size



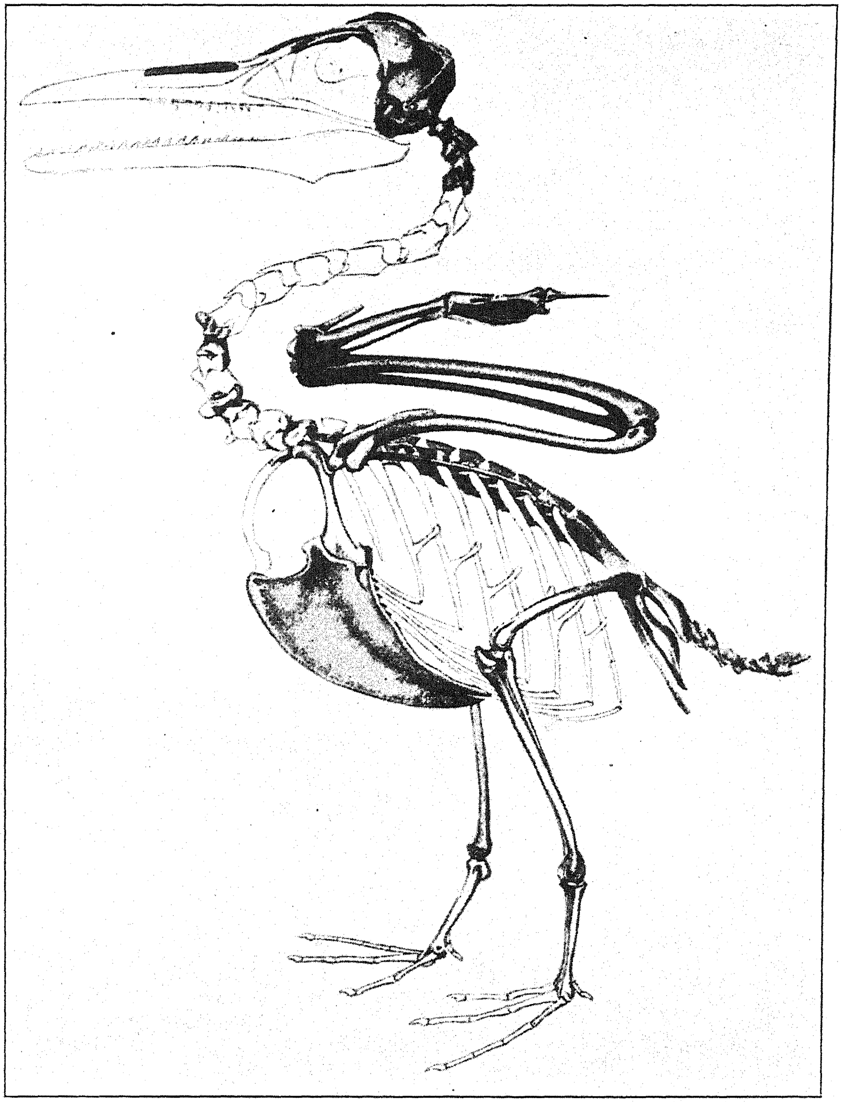
Skeleton of Hesperornis regalis Marsh, One of the Toothed Birds from Cretaceous Formations

From specimen in the U. S. National Museum. This bird is nearly 6 feet in length



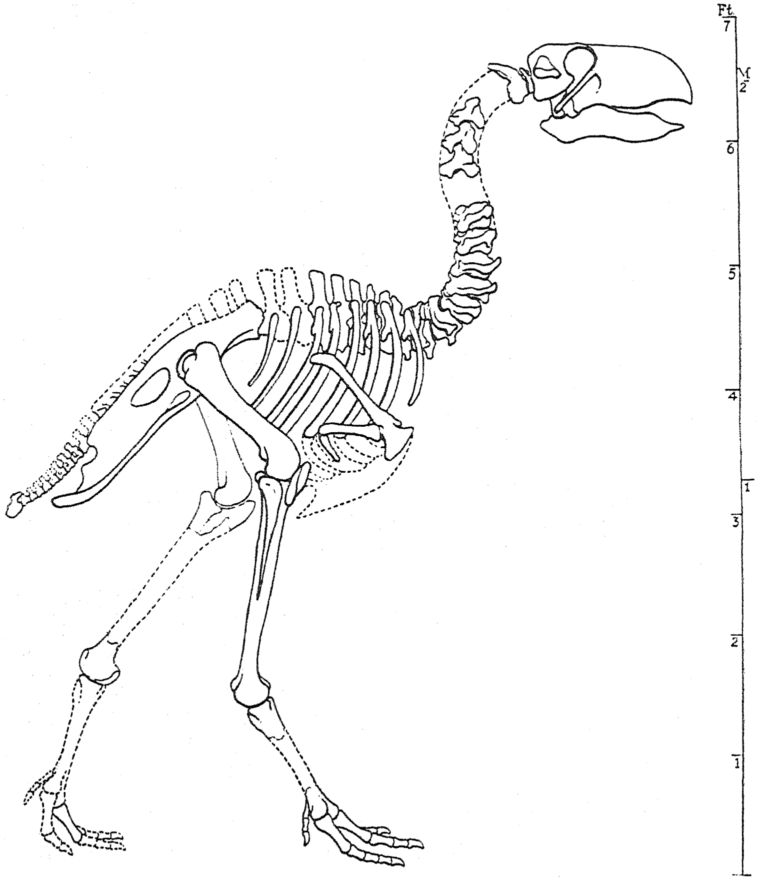
RESTORATION OF THE TOOTHED DIVING BIRD, HESPERORNIS REGALIS

The broad feet are set at such an angle with the body that the bird could not stand erect. (From F. A. Lucas, Animals of the Past, published by McClure, Phillips & Co., 1901)



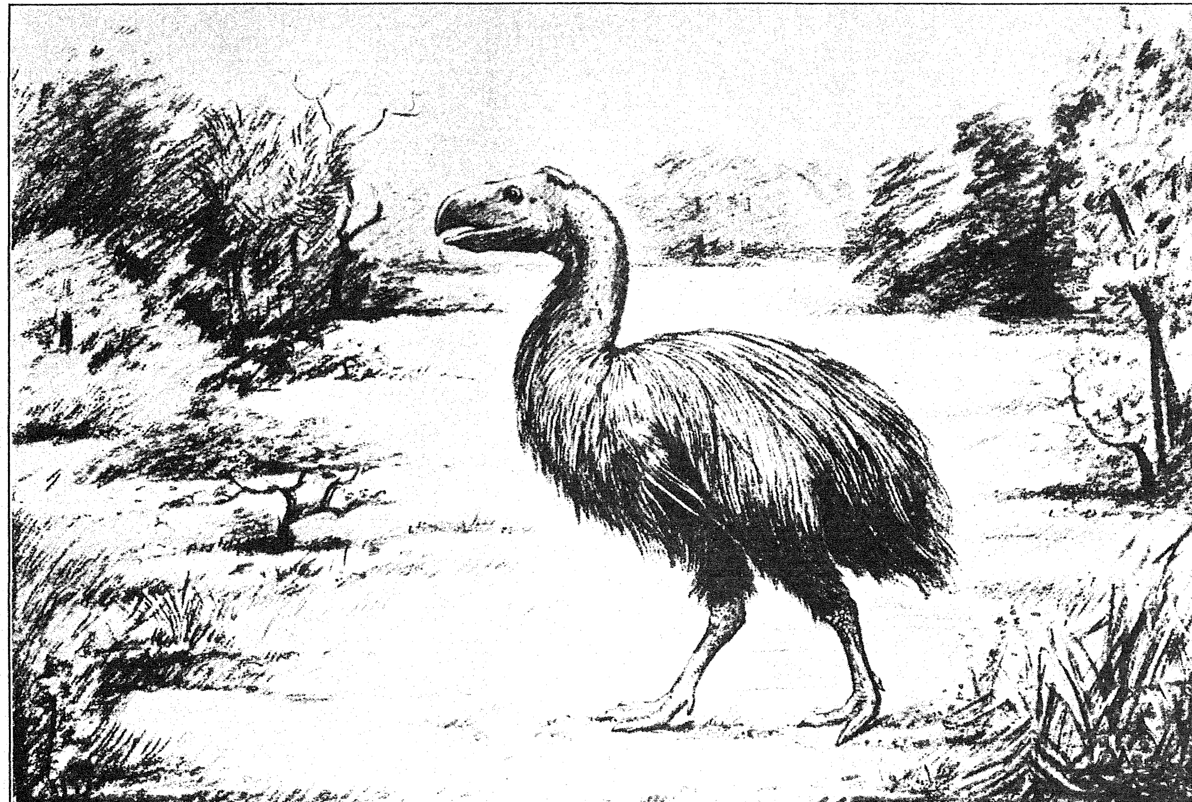
RESTORATION (FROM MARSH) OF THE TOOTHED BIRD ICHTHYORNIS VICTOR FROM THE CRETACEOUS

The skeleton, aside from the teeth and the biconcave vertebræ, is quite similar to that of modern flying birds



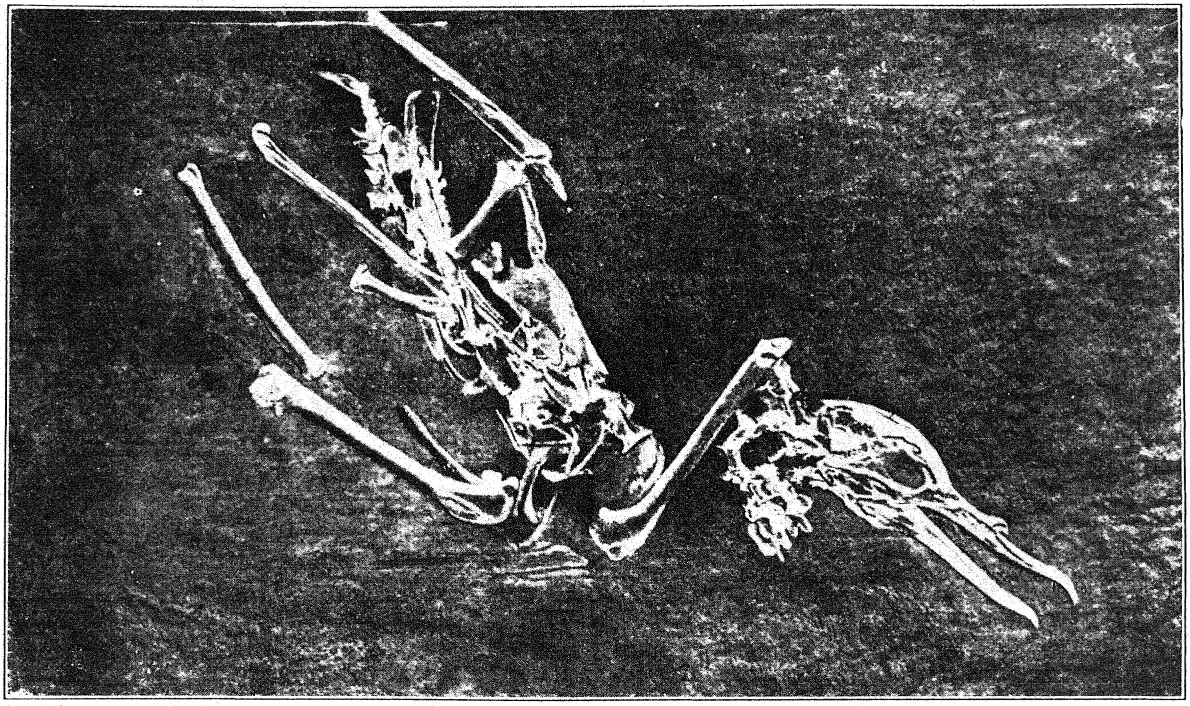
RECONSTRUCTED SKELETON OF DIATRYMA STEINI MATTHEW AND GRANGER, A GIGANTIC, FLIGHTLESS BIRD FROM THE EOCENE OF WYOMING

From specimen in American Museum of Natural History. This species was more than 6 feet tall. (Courtesy of the American Museum of Natural History)



Restoration of Diatryma steini Made from the Skeleton Shown in Plate 6

(Courtesy of the American Museum of Natural History)

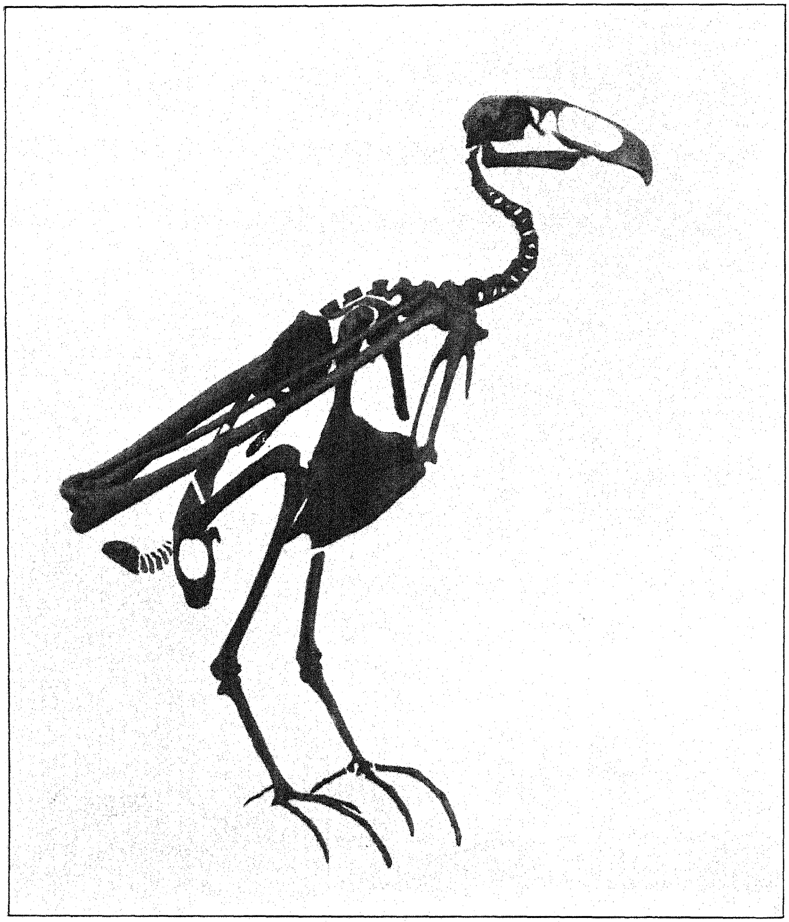


TYPE SPECIMEN OF PUFFINUS DIATOMICUS L. H. MILLER, FROM THE MIOCENE OF CALIFORNIA

This species was closely similar to living shearwaters. (Courtesy of the Carnegie Institution of Washington)

TYPE SPECIMEN OF PALAEOSPIZA BELLA J. A. ALLEN, A PERCHING BIRD FROM THE MIOCENE OF COLORADO

Taken from the type specimen in the Museum of Comparative Zoölogy. Impressions of the feathers may be seen distinctly, particularly in the tail. (Courtesy of the Museum of Comparative Zoölogy)



TERATORNIS MERRIAMI L. H. MILLER, A GIANT VULTURE WITH BROADER SPREAD OF WINGS THAN THE LARGEST CONDOR, FROM THE PLEISTOCENE ASPHALT BEDS OF CALIFORNIA

Photographed from a cast in the U. S. National Museum

RESTORATION OF A PLEISTOCENE ASPHALT POOL AT RANCHO LA BREA, CALIFORNIA, WITH THE GREAT VULTURE TERATORNIS PERCHED AT THE LEFT WATCHING GROUND SLOTHS AND SABER-TOOTH TIGERS

From a painting by Charles R. Knight, in the American Museum of Natural History. (Courtesy of the American Museum of Natural History)

MAMMALOGY AND THE SMITHSONIAN INSTITUTION

By Gerrit S. Miller, Jr.

Curator, Division of Mammals, United States National Museum

[With three plates]

I

Aristotle has said that all knowledge begins in wonder, and, whether we accept his words as expressing the whole truth or only a part of it, we can not fail to recognize that wonder acts as an irresistible stimulus which drives men to exploring every detail of the universe as truly as it sets a monkey to searching out every corner of a cage. Modern knowledge is not the least of the results; and numberless men have found in the gathering and arranging of this knowledge the greatest of their intellectual pleasures. But while men and monkeys have curiosity in common, men alone, so far as we know, possess the attribute that, having done something because of the satisfaction which comes from the doing, they feel constrained to justify their work on grounds of religion, morality, or logic. Thus, in the middle of the eighteenth century, we see Linnaeus, one of the most enthusiastic and indefatigable students of nature that the world has known, printing this invocation on the back of the title page of his Systema Naturae:

O Jehova

Quam ampla sunt Tua Opera!
Quam sapienter Ea fecisti!
Quam plena est Terra possessione Tua!

Again, only 30 years ago, we find the Jesuit Father Heude, whose greatest joy lay in studying the mammals of China and the Philippine Islands, replying to strictures on the superabundance of his publications in somewhat the following manner: That God had created a multiplicity of mammals for the express purpose of testing human ingenuity in finding and describing them, and that the systematic papers complained of by the critics were only the answer to this divine challenge, a duty imposed on their author by his office as priest.

At present, utterances like those of Linnaeus and Heude are not in fashion, but we hear much about the love of humanity as a moral

foundation for research, and also of the economic importance of science as its logical justification. There is no need to doubt the unselfish heroism of a Kissinger and a Moran, refusing pecuniary gain and risking their lives to enable Walter Reed to prove how yellow fever is transmitted; neither can we question the economic benefits to humanity which have come through the work of an Edison; but such conspicuous instances of moral and economic incentive must not be allowed to obscure the fact that these have rarely been the main forces which have induced men to enter the field of scientific endeavor. And, as in the general history of science the moral and humanitarian values were not realized until a comparatively late day, so in the development of the individual worker they seem normally to come to the fore at a period after the scientific bent of the mind has first been fully established. Pasteur furnishes a typical example. Few men have done more for the direct welfare of humanity than he, yet we are told that before he ever dreamed of his studies of fermentation and disease he was a glutton for work, entering the Sorbonne long before the hour when the professor was due to lecture in order to make sure of obtaining a good seat. It was only in after years that this intellectual enthusiasm became directed toward those problems immediately connected with human welfare the solution of which established Pasteur's imperishable fame.

There is nothing to be gained by denying that discovery for its own sake has always been the mainspring of work in all branches of scientific endeavor—including mammalogy, which I propose to discuss. This incentive requires no other apology than an indication of how the knowledge thus gained has contributed to human advancement. Indeed, an understanding of the relationships between the obscure seeker after facts and man's well-being must forever justify the worker in pure research.

Advance of civilization and enlargement of human conceptions have always shown a direct relation to the growth of this knowledge, and, on the other hand, there is reason to believe that civilizations may have been on more than one occasion checked or destroyed because of the lack of it. It has been suggested that the culture of Greece, for instance, may have declined and finally perished through lack of knowledge about the interwoven life histories of a mosquito and a one-celled creature so small that it is able to live in the red corpuscles of human blood and by its activities there to cause the energy-sapping disease, malaria. It is not every kind of mosquito that can carry this parasite, and the whole subject of malarial sanitation therefore depends primarily on a knowledge of the species and ranges of these insects, a knowledge which can only come from studies of the kind usually known as "systematic." A clear understanding of other interwoven life histories like that of mosquito-

man-malaria has wrought incalculable good, but in every instance systematic work pursued first for its own sake has laid the foundation on which the humanly useful structure could be raised.

In some of these life histories mammals play a part. The minute organism which causes the deadly Rocky Mountain fever is brought to the human body by an insect, a special kind of tick, which normally feeds on the blood of ground squirrels, marmots, and other wild animals, but which may occasionally vary its diet by sucking the blood of man. A knowledge of the kinds of mammals with which this tick is associated, and their distribution, therefore becomes highly important from the human point of view, because the disease can be avoided by keeping away from the places where these animals occur, or it can be eradicated by destroying the tick carriers. A similar life chain is now well known, linking up man, rat, flea, and plague. Let it be broken at any link and the disease must disappear. The more practicable way is to eliminate the rat or other mammal, such as the ground squirrel in California or the tarbagan (a large marmot) in Mongolia, which may be a suitable reservoir for the plague-carrying flea—a different insect from the fleas of cats and dogs. But before this work can be successfully prosecuted it is necessary to know what mammals may harbor this particular flea and, by their distribution and habits, thus become menaces to human health. Here mammalogy must be called upon for its knowledge of species and their ranges. The importance of this knowledge will be evident when it is realized that the rat tribe, instead of being limited to the two or three rats and ratlike mammals known by most people, actually consists of many hundred different kinds, each with its particular range, its particular mode of life, and its particular possibilities of serving as an intermediary between fleas and men. So also with the ground squirrels and other carriers of plague fleas. Their number, as revealed by the study of mammalogy, and the intricacies of their possible contacts with man, are vastly greater than is popularly supposed. All of this mass of information must be made available to those who are carrying on campaigns of health.

Centuries ago public opinion forbade the dissection of the dead human body. Dissection of animals and reasoning from analogy were therefore the means by which our forefathers obtained their first ideas of human anatomy and physiology. At present experimentation on living men and women is similarly forbidden, though the time is not very far past when surgeons were permitted to operate on criminals who might thus obtain pardon in view of their service to humanity. To-day, therefore, we must have recourse to physiological experimentation on mammals other than ourselves in efforts to solve some of the most vital problems with which society is confronted. As examples it is only necessary to mention the use

of mammals in the study of bacteriology, in experiments on the transmission of disease, in investigating the relation of foods and the glands of internal secretion to bodily development, and in attempting to solve the enigmas of psychology, heredity, speciation, isolation, and relation to environment. In all of this study an exact knowledge of the specific identity of each animal under observation is needed. Gradually it is being learned that species which are nearly allied may, nevertheless, react quite differently to a given stimulus, such as heat, cold, hunger, or exposure to disease. A primary requirement in experimentation is therefore to know precisely what kind of mammal is being used by every worker in the field, so that results may be accurately compared. The specialist in bacteriology, in psychology, or in genetics is unable to supply this information himself; he must go to the mammalogist for it; and in so doing he furnishes one more example of the way in which human advancement is linked up with the seemingly unimportant pursuit of systematic study carried on for the intellectual satisfactions which it brings.

Turning from these practical matters to the more theoretical aspects of zoology we find conspicuous instances in which generalizations have gone astray for lack of this fundamental knowledge. The following are two good illustrations.

Darwin observed that the wild rabbits inhabiting the islet of Porto Santo, one of the Madeira Islands, were smaller than those of England. Knowing that the Porto Santo rabbits had been introduced by the Portuguese about the year 1419, he concluded that a decrease of "nearly 3 inches in length and almost half in weight of body" had taken place in four and one-half centuries. As it was supposed in Darwin's time, and for half a century later, that all the wild rabbits of Europe belonged to a single race, this conclusion as to the animals on the island seemed justified, and the story of the Porto Santo rabbit found its way into many treatises on evolution. But subsequent systematic study of the rabbits showed that there are in reality two races, a large one in central Europe and a smaller one in the Mediterranean region and the Iberian Peninsula. Being unaware of this fact, Darwin compared the Porto Santo rabbit with the wrong animal and so arrived at a false conclusion which has been given wide circulation in popular textbooks. Recently a German author was engaged on the problem of the changes which have taken place in mammals under the influence of domestication. He believed that domestication tends to bring about marked changes in the form of the skull. As his most striking example of such a change he compared the skull of the domestic ferret with that of the wild European polecat. He had no difficulty in finding conspicuous differences, which are clearly apparent in his published photographs of the two

skulls and which he unhesitatingly attributed to the effects of domestication on one of the animals. Here, also, as in Darwin's case, was an attempt at generalization without accurate systematic knowledge. Had the ferret been compared not with the European polecat but with an Asiatic species which is probably the actual wild ancestor, no such differences would have been found; in fact, the conclusion would then have been reached that domestication had produced no perceptible change. These concrete examples will serve as an index to the importance of systematic study as the basis for all reasoning about the history of life.

There are many other subjects of broad general interest to whose understanding the study of mammals may contribute. Why, for instance, do the different mammals live where they now exist? Every one knows in a general way, that each kind of mammal has its home territory outside of which it cannot be found; that polar bears will not be seen swimming in the Amazon, and that elephants will not be encountered in the woods of Maine. That the hippopotamus and lion must be sought in Africa, the kangaroo in Australia, and the walrus on the ice floes of the far north are facts within easy reach of every reader; but there are relatively few persons who know that the lion and hippopotamus have left their bones in England, that elephants have lived in all parts of the United States, that remains of the walrus have been found as far south as Charleston, South Carolina, and that camels and wild horses of many kinds have flourished in America, some of them north of the Arctic Circle, only to become extinct before the arrival of the white man. Equally unknown, perhaps, is the fact that we have no undisputed evidence that kangaroos and duckbills ever occurred anywhere but in Australia and in some neighboring islands.

The restriction of the ranges of wild animals occasioned by the advance of civilization is now attracting so much notice that most of us fail to realize how universally the same process is going on without human interference, and how much more destructive to particular forms of life is nature than man. Parts of the Sahara were once wooded; with the drying up of these forests most of the animals which inhabited them must have perished. A similar process on a smaller scale seems to be now under way in the Kalahari region of South Africa. Many animals which lived in the central United States or in southern Europe under congenial arctic climates during the Ice Age have been killed or driven far to the north by the change to warm conditions which they could not bear. The mere spreading of forests over grassy steppes has undoubtedly been responsible for the disappearance of many more mammals than have ever been exterminated by man. On the other hand we have recently

learned that the opposite process is actively going on; that is, that some mammals are now extending their ranges. In the northeastern United States cottontail rabbits are moving northward and eastward; coyotes, in spite of organized campaigns for their extermination, are spreading toward the north in Canada and Alaska and possibly toward the east in the United States; even the slow armadillo has pushed the limits of his territory northward across the State of Texas during the memory of men now living.

All of this shows that the species of mammals, like the lands on which they live, are never still. Life moves about on the surface of the earth in just the same way that this surface is continually moving—being raised, worn down, wetted, dried, covered, denuded, heated, cooled. The geographical distribution of mammals to-day is the result of a long series of wanderings. Something of the history of the earth's land masses can therefore be inferred from the characteristics of the mammals which inhabit them. The striking peculiarities which distinguish the pouched kangaroos and the egg-laying duckbills of Australia from all the mammals known to occur elsewhere point unmistakably to a long geographical isolation of Australia; the similarity of the bears, wolves, hares, and ground squirrels of Alaska to those of eastern Asia points to a very recent land connection between these most nearly contiguous portions of the eastern and western worlds.

Man in the early stages of his development, before the discovery of artificial means for overcoming natural obstacles, was probably subject to much the same limitations as other mammals. When seaworthy boats were unknown he must have sought ancient land connections to enable him to travel from island to island and from continent to continent in precisely the same manner that elephants and horses sought these natural highways. Hence an adequate knowledge of the migration routes by which mammals have arrived at their present homelands ought to throw light on the subject of prehistoric human dispersal.

The great problems now facing mammalogy may therefore be summed up by the words: Description, distribution, relationship, history. Description is the fundamental work on which all subsequent structures must rest. To attempt the study of distribution, of relationships, of history, or of the exact economic value of mammals, without a previous accurate knowledge of the different kinds would be as futile as to attempt to run a railway into a new country without first surveying the land to be traversed.

II

Mammalogy, then, is more than the hobby of certain men endowed with a strange curiosity. It is the scientific study of the mammalia, the gathering and arranging for all who need them, of facts about those animals which possess, at least during some phase of their existence, hair and milk. The word mammalia appears to have been first used about the middle of the eighteenth century, by the Swedish naturalist Karl von Linné, better known as Linnaeus. Strange as it may seem, there had not been, up to that late day, any distinctive name by which to designate the great assemblage of animals to which we ourselves belong, together with our relatives the whales, duckbills, bats, apes, and others, the most obvious group characteristic of which is that the young must be fed on milk. The term quadruped could not be used, for this is equally applicable to the hairless, milkless lizard and tortoise. Linnaeus therefore took the Latin word *mamma*, the name for the gland by which milk is secreted, and telescoped it with the word *animalia*, animals. Mammalia, shortened from mammanimalia, was the result, and we, in English, have made therefrom our vernacular word mammal; by adding a Greek termination meaning discourse we have further produced the technical term mammalogy. Other languages have not followed our example. Instead of using some form of the Linnaean word the French, for instance, call these animals "mammifères," bearers of milk glands, while the Germans know them as "Säugethiere," or beasts that suck.

As now used, the term mammalogy applies primarily to what is known as the systematic study of mammals, the main object of which is to find out exactly how many kinds of mammals there are in the world, exactly where each kind lives, and exactly what are the relationships of these creatures to each other and to their predecessors now gone from the ranks of living things.

This may seem on the face of it not a large undertaking. The average person not specially interested in wild life may know as many as 20 or 30 different kinds of mammals; or, if he lives near a good zoological garden, 50 or 75. Actually, in North America alone we have discovered about 2,500 recognizably distinct kinds, and the work of enumeration is not yet finished; from an area in Eastern Africa scarcely one-tenth as large as North America, the collections of the Smithsonian Institution include representatives of no less than 526 kinds, all of them different from those found in any part of the American continent. The Malay region with its innumerable islands, and South America with its astonishingly contrasted jungles, plains, and mountains, swarm with special sorts of mammals whose existence is unsuspected by anyone not a student

of the subject. When, generations in the future, the count shall have been completed, the total number will certainly be found to exceed 20,000. Imagine behind these living mammals the long lines of extinct ancestral and related species reaching into the past and preserved as fossils, and we may form some imperfect idea of the ground to be worked.

The exploration of this ground by the mammalogist divides itself into two major phases: The collection of material in the field and the study of it in the museum. The difficulties of mammal collecting are greatly increased by the fact that the majority of the mammalian population is made up of small or nocturnal creatures which elude direct observation. While the larger mammals can be shot, the smaller ones must be trapped. For that purpose the well-equipped collector goes into the field with an assortment of traps specially selected for the capture of mammals of the most varied kind and for use in the most varied situations. To use them effectively he must exercise his ingenuity and apply his knowledge in deciphering the records which mammals leave behind them; a path or runway through the grass here; a tunnel under rotting leaves there; footprints in snow, mud, or sand; holes and mounds which show where some creature has been digging for roots or grubs, or to make a shelter; piles of the emptied shells of seeds, nuts, snails, mussels, or crayfish—in short, a complicated code of signs, the right interpretation of which will lead to success, and the misunderstanding of which may bring amusing failure, as on one occasion when a collector caught nothing but mole crickets after setting many traps in tunnels which he supposed had been made by small shrews.

After being trapped or shot, a mammal must be prepared by the removal of the skin and the drying of the skull or skeleton, as these parts serve the most useful purpose in the subsequent studies.[1] Many specimens, particularly of the smaller kinds, are kept entire in alcohol. When field work has been pursued long enough in one place to have furnished representatives of most of the mammals which are found there, the collector moves on to a locality where differences in soil, vegetation, or climate give promise that other kinds may be found. In this way a systematic survey of an area is made. After the specimens obtained in the field are received at the museum it is necessary to arrange them so that they may be available for study and safe from the danger of deterioration. To begin with they must be catalogued, numbered, and labeled in ac-

[1] Directions for Preparing Specimens of Mammals, a 22 page illustrated pamphlet, is issued by the Smithsonian Institution (Bull. U. S. National Museum, No. 39, pt. N, ed. 5, revised, 1925).

cordance with a system by which every separate part preserved—skin, skull, skeleton, or any of the soft parts which may have been placed in alcohol—can be identified as having come from a given individual. Here the work of trained bookkeepers is needed. Skulls and skeletons are next put through processes by which their dried flesh is removed. This requires the services of special preparators. When finally ready for permanent installation in the collection the smaller bones are placed in glass tubes or pasteboard boxes, the larger ones in trays or drawers; then all are arranged in cases according to some scheme of classification which will permit the ready finding of any individual specimen needed for examination. Skins of small mammals, up to about the size of a house cat, are filled to natural size with tow or cotton and then dried lying flat, back up, with the fore legs extended alongside of the neck, and the hind legs drawn backward, parallel with the tail. This is usually done in the field. Preservation in uniform, conventionalized manner is essential to the comparison of specimens with each other. Larger skins are tanned and laid away in drawers or trays or hung from bars. Each is labeled with locality, date of capture, name of collector, and the serial number which serves to identify the corresponding skull or other parts. In a large museum, where the number of specimens runs into the scores of thousands and the growth of the collection is rapid, a special force of assistants is required to look after the details of installation and arrangement.

It must be understood in this connection that the mounted specimens ordinarily seen by the visitor do not constitute the real collection. The main object of a great museum is to promote research, that is, to advance our knowledge of the world we live in, and not merely to display beautiful examples of the taxidermist's art. Research requires an abundance of material in convenient form for study—conditions which are not met by a few mounted specimens locked in glass cases. The exhibition series is therefore nothing more than a group of selected individuals which can be spared from the real collection. I say spared because practically every skin which is mounted and placed on exhibition is condemned to death from the slow but inevitable ravages of time and sunlight.

The study series, as the real collection is called, is kept in tightly closed wooden or metal cases where light cannot penetrate and where the specimens will be as safe from deterioration as human ingenuity can make them. In the National Museum, which is under the direction of the Smithsonian Institution, there were in June, 1928, about 214,000 specimens of mammals in the study collection, while those on exhibition totaled barely 1,400.

III

Study of a mammalian collection requires as a first step classification of the material by orders, that is, determining whether a given specimen represents, for instance, the great group of hoofed mammals (ungulates), or the flesh-eaters (carnivores), or the gnawers (rodents), or the trunk bearers (elephants), or the true flying mammals (bats), or the fish-like mammals (whales and porpoises). Next the specimens are sorted out into the successively smaller subdivisions of each order, that is, into families (as, among the flesh eaters, the bear family, cat family, and dog family); into genera (as, in the dog family, the true dogs, the foxes, the fennecs, and the African hunting dogs); and into species (as the dog and wolf, two species of the true dogs as distinguished from foxes, fennecs, and African hunting dogs). Finally, each species is separated into its subspecies or the local forms which it assumes in different parts of its range (as the huge wolf of our northern forests, the smaller wolf of the Arctic tundras, the dark-colored wolf of Florida, and so forth.)

Subspecies are distinguished from each other chiefly by size, by shades of color, and by slight peculiarities in the proportionate lengths of various parts (feet, ears, tail), usually small differences not involving deep-lying elements of structure and, more important still, not always present in every specimen. Species are determined by constantly present peculiarities of the same general type, possibly greater in degree than those which distinguish subspecies, and by differences in actual color and in color pattern, quality and distribution of the fur, shape and size of the teeth, or of the individual parts of the teeth, shape and size of the individual bones of the skull. Genera are determined by still greater peculiarities in structure, often including differences in the number of teeth, the number of toes, and so forth, the essential feature of a genus being that it includes a group of species either actually or as a reasonable possibility. Families are determined by larger characters of the same kind as those which distinguish genera, and each family is primarily a catagory which includes or might include a group of genera. Finally, the orders of mammals are distinguished from each other by various combinations of the largest and most fundamental characters of all—such as (*a*) the processes of reproduction (whether the young are hatched from eggs laid in nests or whether they are born alive; and, if born alive, whether they have or have not been first brought to high development by a special nutritive organ); (*b*) the type of the limbs and feet (whether hoofed, clawed, or serving as paddles, or as true wings); and (*c*) the type of the teeth (whether chiefly adapted to grasping, as in dolphins, to cutting, as in cats, to chopping, as in

bats and moles, to grinding, as in elephants, cattle, and horses, to a combination of cutting and grinding, as in rats and beavers, or to all-round utility, as in men and pigs).

Systematic mammalogy therefore resolves itself into the investigation of all of these features and of any others which may assist in the accurate determination of different kinds, and in the grouping of these kinds according to their relationships. In all of this part of the study it is of prime importance to distinguish between those peculiarities which are constant specific characters and those which are individual features of the sort normally occurring in the two sexes and in the various ages of one animal. Many specimens of each mammal must be examined and compared before the differential peculiarities can be clearly distinguished from those due to the diverse sorts of individual variation. Many more are needed to determine the status of local races, because a series from one place may be obviously different from a series from another, when one or two specimens from each would be indecisive. After this more specimens of each kind are needed from as many different localities as possible, in order to determine the limits of geographical ranges. Field observations such as those which have contributed to our knowledge of birds are of relatively little value in studying mammals, because most mammals keep themselves hidden from human sight.

In mammalogy, as in every other branch of present day knowledge, an important element in the routine of the active worker is the task of keeping abreast with the ever increasing current of literature. Arising from the work done by members of museum staffs and by individual students, given out through the channels of books, periodicals, and the journals of scientific societies, finding its source in the two Americas, in England, France, Spain, Belgium, Holland, Denmark, Norway, Sweden, Germany, Italy, Hungary, Russia, the Malay States, Java, Australia, and Japan, there flows a growing stream of publications about mammals. To be ignorant of the information which these treatises, monographs, papers and notes contain would be a fatal handicap to anyone who aspired to become a serious student. One of the recognized elements of the work in our larger museums therefore consists in maintaining a constant familiarity with the literature of mammalogy, a task which is lightened by the aid of the Zoological Record (London), Biological Abstracts (Menasha, Wisconsin), the cards issued by the Concilium Bibliographicum (Zürich) and the lists of current publications which appear quarterly in the Journal of Mammalogy. Trouessart's Catalogus, Palmer's Index Generum Mammalium and Sherborn's Index Animalium are other well known standard works. The more important mediums of publication in which the essential part of the recent literature has appeared are as follows: In Washington we

have the series of 51 numbers of North American Fauna founded by Merriam in 1889 and issued at irregular intervals by the United States Department of Agriculture; under the direction of the Smithsonian Institution many important monographs and papers have appeared in the Smithsonian Contributions to Knowledge, the Smithsonian Miscellaneous Collections, and the Proceedings and Bulletins of the United States National Museum; finally the Biological Society of Washington has provided a convenient medium for issuing short papers in its proceedings. Next in importance among American publications have been those issued by the American Museum of Natural History in New York—Bulletins, Memoirs, and Novitates. Contributions have appeared in many other places, notably in Berkeley, Cambridge, Chicago, and Philadelphia, but the essential part of the recent history of American mammalogy has been written and printed in Washington and New York. In England publication has centered in the Annals and Magazine of Natural History and the Proceedings of the Zoological Society of London, serials which have been issued in unbroken line for a century. In Germany most of the important work has appeared in the Sitzungsberichte naturforschende Freunde zu Berlin and in Wiegmann's Archiv für Naturgeschichte. Other media of publication have been the Arkiv för Zoologi in Stockholm, the Videnskabelige Meddelelser fra Dansk Naturhistorisk Forening, and E. Museo Lundii in Copenhagen, Notes from the Leiden Museum in Holland, Annales du Musée du Congo Belge in Belgium, Boletin de la Real Sociedad Española de Historia Natural in Spain, Atti della Societa Italiana di Scienze Naturali, and Annali del Museo Civico di Storia Naturale di Genova in Italy, the official publications of the museums in Tiflis and St. Petersburg, the Bulletin of the Russian Academy of Science, the Journal of the Bombay Natural History Society, and the Journal of the Federated Malay States Museum, in Kuala Lumpur. Three special periodicals are now devoted to the subject of mammalogy: the Journal of Mammalogy, issued by the American Society of Mammalogists, the Zeitschrift für Säugetierkunde published by the Deutsche Gesellschaft für Säugetierkunde, and the Revue Française de Mammalogie, one of the official organs of the Société Ornithologique et Mammalogique de France.

IV

The beginning of mammalogy dates from the middle of the eighteenth century. At that time two naturalists, Linnaeus in Sweden and Brisson in France, gathering together and summing up the knowledge of vertebrates which had been accumulated during two and a half centuries of world exploration, laid the foundation

on which the present structure has been built. Much information had already been published, but the definite course of procedure which we are following to-day was not established until Linneaus perfected his system of classification and nomenclature and Brisson applied to mammals an enlarged scheme of synoptically tabulating the characters by which the different groups are distinguished from each other. Trivial though such innovations may appear, they actually proved to be of so much importance that mammalogy as a special branch of zoology took its date from them, and the work of earlier naturalists retired to a position of antiquarian interest. The reason for this should be apparent to anyone who has grasped the idea of the great number of mammals to be written about; the appearance of any convenient scheme for handling the rapidly increasing mass of facts, when hitherto no such devices had existed, would necessarily mark an epoch. The system of Latin names perfected by Linnaeus and regarded by the general public as a form of mystification is nothing but a time-saving device, a tool so useful that, in the absence of something better, the scientific study of mammals could not have gone on without it. Such also was Brisson's system of tabulation.

In the year 1758 Linnaeus was able to include only 86 mammals in the tenth edition of the Systema Naturae, his boldly conceived two-volume review of the living things of the world. A century later Baird, the second Secretary of the Smithsonian Institution, knew 220 kinds in North America alone, while now, 70 years after Baird and 175 after Linnaeus, we are acquainted with about 2,500 kinds in North America, or about 30 times as many as the whole world was supposed to contain at the time when the modern study of mammalogy began. To trace all the steps by which this increase of knowledge has been made would be the subject for an entire book. Here it will be possible merely to indicate some of the most important. At first the subject was small and every author felt himself qualified to describe all the mammals in existence. This feeling of self-sufficiency arose from the ignorance which prevailed then. There were few known mammals to write about, and the system by which they were classified was so simple and artificial that there was no difficulty in referring each species to its proper place. Great museums had not been established and specially equipped collecting expeditions were undreamed of. The descriptions and notes made by travelers and published as incidental matter in their accounts of strange lands were the chief source on which the European naturalist was forced to depend. Work done under such conditions was necessarily incomplete, but it was also pleasing in its appearance of simplicity. Indeed, the complicated nature of the facts could not be suspected and it was therefore possible to regard each species and each higher category as an entity unconnected with any other except

in the sense that the members of a lower category might be looked upon as so many examples of the type represented by the larger group to which they belonged. To illustrate: Lion, tiger, and puma were examples of the cat genus; the cat genus, dog genus, and bear genus were examples of the carnivore order; the carnivore order, rodent order, and bat order were examples of the mammal class; the mammal class, bird class, and reptile class were examples of the animal kingdom. There was no thought of actual relationship by the bonds of common descent, no idea that the boundaries supposed to separate species from species or order from order had not always been as sharply drawn as they appear to be now. For these early investigators the animal kingdom was a definite and finished product, a thing made up of parts as distinct from each other as the stones in a wall. When once these parts should have been found, catalogued, and described the work of mammalogy would be done. Under the influence of conditions and conceptions such as these it was natural that treatises on mammals should follow the Linnaean precedent of concise synoptical treatment, briefest possible description, relatively elaborate citation of the work of previous authors, and absence of discussion or speculation as to the meaning of the things which were being catalogued. Books of this general type were published by Boddaert (1785) in Holland, by Erxleben (1777), and J. B. Fischer (1829) in Germany, by Desmarest (1820) and Lesson (1827) in France, and by G. Fischer (1814) in Russia. A work which exceeded all the others in size and in elaborateness of treatment was the great "Säugthiere" (Mammals) of the German Schreber, 13 quarto volumes illustrated by 763 plates; the first volume appearing in 1775 and the last supplement, by A. Wagner, issued in 1855.

The period during which the writing of all-inclusive works on the species of mammals by one man was supposed to be possible ended about the middle of the nineteenth century. Since that time the largest units of publication have been monographs of single orders, enumerations of the species of mammals known to occur in limited areas, and treatises on the classification of mammals at large with discussions of the derivation and interrelationships of the higher groups. Notable works of this last kind have been written by Flower and Lydekker in England (1891), Weber in Holland (1904 and 1927–28), Gregory in the United States (1910) Cabrera in Spain (1922), and Winge in Denmark (1923–24). Each of these books stands as a landmark along the course of development of this very important branch of the subject. During the past 40 years a type of publication which was comparatively little known before 1850 has become dominant, namely the short paper containing descriptions of a limited number of newly discovered mammals, lists of the species found in particular areas, or the elucidation of special,

limited problems of classification, distribution, or relationship. The advance in knowledge since 1890 has been so rapid that every student knows that the preparation of a complete work on the mammals of the world is beyond the capacity of any individual worker. But fortunately, near the beginning of this period, Dr. E. L. Trouessart of Paris had the foresight to publish a Catalogus Mammalium tam viventium quam fossilum, in which the results of the systematic study of mammals during the 140 years following Linnaeus were summarized. It contains the enumeration of 4,423 recognizably different kinds of living mammals together with references to the publications in which descriptions of each kind may be found. Since 1898, when the last part of the Catalogus appeared, not less than 8,700 new names have been added to the list of living species and subspecies; and the process is continuing at an undiminished rate of about 250 a year.

The recent development of mammalogy has been mainly dependent on two factors—interest in the problems having to do with the nature and history of the life which now exists in the world, and the finding of a technique by means of which the study could be successfully carried on. The interest was aroused by Charles Darwin and the stimulating controversies which have never ceased to grow from his writings; the technique was worked out by an Associate of the Smithsonian Institution, Dr. C. Hart Merriam.

The effect which Darwin's work has had on the general concept of the life of our globe is too well known to require more than brief mention here. Welding together, by the force of his genius for observation and clear reasoning, the scattered existing ideas of an evolutionary explanation of vital phenomena, he made it impossible longer to regard the different kinds of animals and plants as the fixed and rather simple elements in a finished and immutable structure. Convinced by the evidence so clearly set forth by Darwin the naturalist of to-day regards all living things of the past and present as phases of one great life process whose history he is slowly learning to trace—through a period covering millions of years—and whose progress depends not on fixity and simplicity but on capacities for never-ending change and for the production of results complex beyond the possibility of realization by the untrained mind.

While the point of view from which the study of mammalogy had been regarded was thus profoundly altered by the Englishman, Darwin, the means by which the new approach could be effectually made were developed by the American, Merriam. His interest grounded by the personal influence of Professor Baird and stimulated by the example of the brilliant contemporary development of ornithology, Merriam brought to the systematic investigation of mammals a mind

24034—29——27

endowed with energy and foresight. And in his undertaking as in many others, success was furthered by the coincidence of two unrelated events—the awakening of this interest and the decision of a manufacturing company, which had hitherto been making clothes wringers, to put on the market a cheap and convenient mouse trap. The "Cyclone" trap, the first of the now familiar small traps of the deadfall type, made its appearance during the later eighties of the last century, at exactly the time when Merriam was beginning to realize that his predecessors from Audubon and Bachman through Baird to Coues and Allen had not completed the study of mammals in North America. Armed with an effective trap he was able to apply to the investigation of mammals the principles which he had learned from the study of birds, the salient features of which are the bringing together and minute comparative study of large series of specimens—all uniformly prepared—from every possible locality. Had this not happened at this particular time, the recent history of mammalogy would have been different throughout the world.

Before the time when the "Cyclone" trap and its successors were available, the kind of field work which I have briefly described was unknown and the systematic collecting of the abundant smaller and more interesting mammals was an impossibility. I remember my own first attempts at field work, when the only traps to be had were clumsy wooden objects stained bright red and shaped like a round flat cheese with the side bored full of holes through which the victims were expected to thrust their heads in order to be choked. Not ineffective for house mice, these traps became exasperating failures when carried out to the fields and woods. A summer's industrious work with them failed to procure me a single individual of the short-tailed shrew or the red-backed mouse, two of the common mammals in the woods near my home. Then came word of the new technique and with it six dozen "Cyclone" traps. Immediately I was able to get all the specimens that I could prepare.

In 1894 these methods were demonstrated at the British Museum, where they were adopted by Oldfield Thomas, the man who has added more to the systematic knowledge of the mammals of the entire world than any other one investigator. They rapidly spread to Germany, France, Russia, and Japan, and they are now universally employed wherever mammals are studied.

The development of mammalogy in North America, like that of so many other branches of natural science, is heavily indebted to the explorations begun in the fifties of the last century, which preceded the laying of the first transcontinental railroads. The surveying parties sent out by the Federal Government were accompanied by field naturalists who made collections of surprising extent and value. The mammal specimens all came to the Smithsonian Institution,

where they were studied and reported on by Professor Baird, whose Mammals of North America, which appeared in 1859 as Volume VIII of the Pacific Railroad Survey Reports, gave the most adequate summary of the North American fauna ever worked out by the older methods. It remained the standard authority on the subject until Merriam, 30 years later, began to revolutionize our knowledge of mammals. During the period between Baird and Merriam the Smithsonian Institution dominated the field of mammalogy in North America. Except for relatively small collections in the museums of Philadelphia and Cambridge no important mass of material for study existed outside of Washington, and at that time the Smithsonian was the only scientific agency in Washington engaged on this particular branch of research. Important works which were published during this period, either by the Smithsonian Institution or under its inspiration, are Harrison Allen's Monograph of the Bats of North America (1864), J. A. Allen's The American Bisons, Living and Extinct (1876), Coues' Fur-bearing Animals (1877), Coues and J. A. Allen's Monographs of North American Rodentia (1877), J. A. Allen's History of North America Pinnipeds (1880), and True's Review of the Family Delphinidae [dolphins and porpoises] 1889. Excellent though all of this work may have been when judged by the standards of its time, the relatively small accretion which it brought to our knowledge is shown by the fact that True as late as 1885, was able to list only 363 mammals as ascertained to inhabit North America. This is an apparent increase of 143 over the 220 of Baird; but to make the comparison a fair one the 146 bats, seals, sea-cows, whales and porpoises, which True enumerated in his paper, must be subtracted because they were not dealt with by his predecessor. The advance made during these years is thus seen to be insignificant compared to the sudden leap forward inspired by the adoption of the new technique.

The present phase of mammalogy in North America began with the founding, in 1886, of a Division of Ornithology and Mammalogy under the United States Department of Agriculture. This division, which subsequently grew into the Bureau of Biological Survey, was organized by Doctor Merriam and directed by him until his resignation in 1910. One of the primary objects of the survey was to map the geographical distribution of the mammals and birds of North America, the related work on plants and insects having already been provided for. At its outset this undertaking was met by the difficulty that the kinds of mammals, when systematically collected, proved to be more numerous than had been supposed. Consequently the first step toward accurate mapping was necessarily to take a census of the mammal population and find out exactly what and how many were the kinds to be mapped. In 1885, as we have seen, the number was

supposed to be 363; by the end of the year 1900 it had been increased to about 1,450. Subsequent counts showed 2,138 in 1911 and 2,554 in 1923.[1]

Merriam gathered about him during the nineties a corps of assistants whom he trained in methods of work in both field and museum—an invaluable experience, as I personally know. The group of mammalogists thus formed, together with Dr. J. A. Allen of New York, an older man than Merrian, but profoundly influenced by him from about 1890 until Allen's death in 1921, have been the workers to whose efforts the advance in North American mammalogy has been mainly due.

To review the details of actual present-day work in mammalogy throughout the world would carry us beyond the limits of this article. In general it may be said that the chief advances are being made by the efforts of large museums and of governmental agencies; relatively little is being accomplished by universities in the field of systematic research in mammalogy, though ably conducted courses of instruction have recently been established, notably at Harvard, the University of Wisconsin, and the University of California; private effort is resulting in the accumulation of many valuable specimens and observations, but it has had no effect on the general course of events except as it may have contributed to the development of museums—witness the remarkable work of Dr. W. L. Abbott for the Smithsonian Institution in exploring the Malay Archipelago, and the generous subsidy of the Duke of Bedford to enable the British Museum to carry on studies of mammals in China and Japan.

In the United States the most important agency, as far as the study of North American mammals is concerned, has been and still is the Biological Survey under the United States Department of Agriculture. The United States National Museum, a branch of the Smithsonian Institution, has avoided duplication of the work of the survey and has turned its attention to the mammals of the West Indies, Eastern Asia, the Malay region, Australia, Europe, and Africa. In New York the American Museum of Natural History is building up large collections from North, Central, and South America, from China, Mongolia, and other parts of Asia, from Australia, and from Africa. The Museum of Comparative Zoology in Cambridge has made important contributions to our knowledge of the mammals of China and Africa. In Chicago the Field Museum of Natural History has accumulated extensive collections from western North America and from East Africa; it is now actively engaged in South America. The Museum of Vertebrate Zoology of the University of California, founded by private endowment, has

[1] See the List of North American Mammals 1923, issued by the Smithsonian Institution as Bull. U. S. National Museum, No. 128, Apr. 29, 1924.

concentrated its efforts on the fauna of western North America. No work of importance to the general development of recent mammalogy has been done by the museums of Canada, Mexico, or the South American Republics. In Europe the greatest contribution to the systematic study of mammals has been made by the British Museum. Adopting the new technique in 1894 and supported by generous contributions of money and personal services from men who recognized the breadth and interest of the field thus opened, this museum has built up a collection of mammals which surpasses that of any other institution in the world in the number of different kinds which it includes and in the general fullness and evenness with which the faunas of every part of the globe are represented. Its field is not limited to any particular region, though, like the Smithsonian Institution, it has avoided duplication of the work which was being done by the Biological Survey. Next to the British Museum the most active European agency in the recent development of mammalogy has been the Museum für Naturkunde in Berlin. Here, under the stimulus of the late Prof. Paul Matschie, especially important collections of ungulates and primates have been brought together; but the field of activity has not been limited to these groups; it has covered the mammals of the world outside of North America. France, a leader during the first half of the nineteenth century, has, throughout the present phase of mammalogy, remained inactive except for the production of the Catalogus Mammalium, the book to which every general worker is more indebted than to any other. In the remaining European countries much local work has been done, but this does not here concern us. Contributions to the broad development of mammalogy have come from Stockholm (Africa, South America, Malay region), Leiden (Malay region), Brussels (Africa), Madrid (South America, Africa), Turin (South America), Genoa (Malay region), and Vienna (Africa). In Russia the museums of St. Petersburg, Moscow, and Tiflis have directed their efforts mainly to the working out of the Russian and northern Asiatic fauna. One of the finest examples of successfully directed field work in the Old World is furnished by the Mammal Survey of India carried on by the Bombay Natural History Society in conjunction with the British Museum. Very important results have also been obtained in the Malay region by carefully planned explorations directed from the Federated Malay States Museum at Kuala Lumpur.

Though taking no part in the active development of the subject, the Smithsonian Institution has been closely associated with the recent advances in mammalogy. Merriam began his studies under Secretary Baird, and throughout his active period in the Department of Agriculture he was an honorary associate of the Smithsonian. The great collection of mammals brought together by the Biological

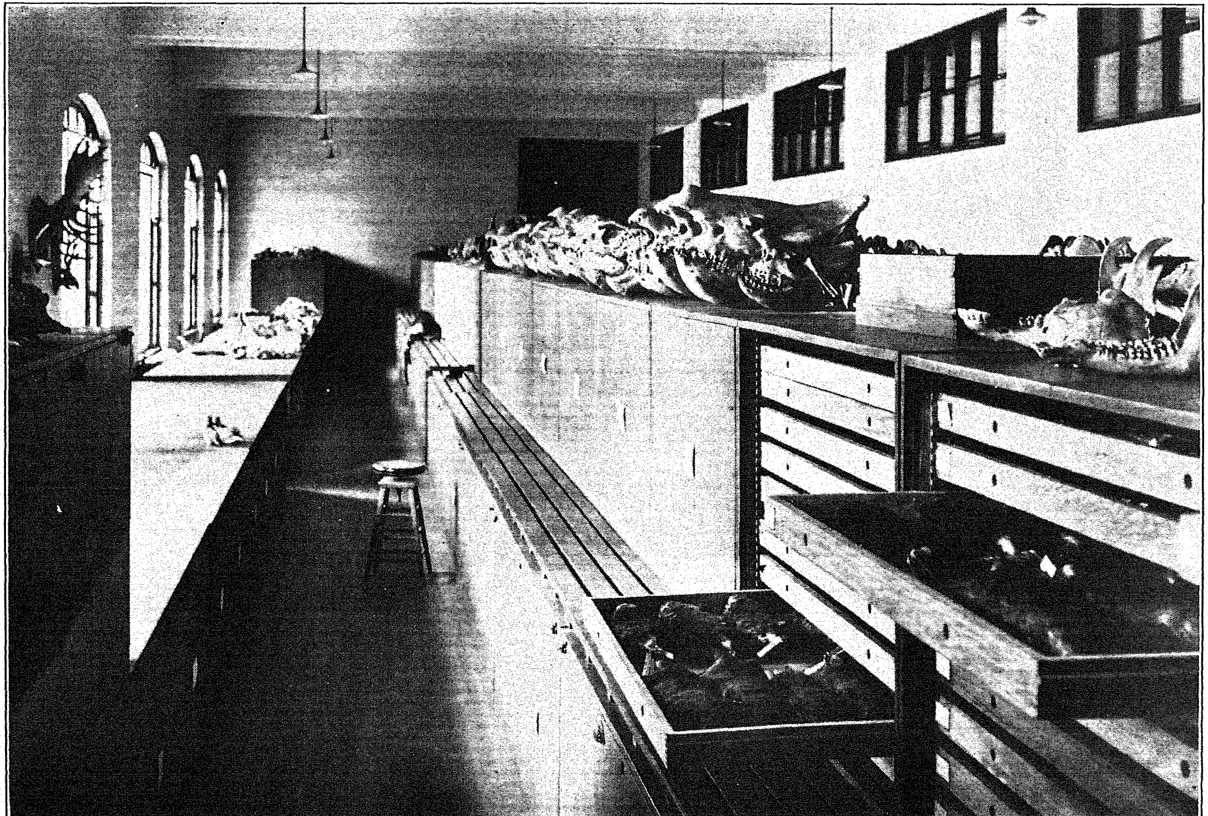
Survey has been, from the first, cared for in the National Museum, one of the branches of the Smithsonian. Finally the Smithsonian Institution, by directing its efforts into fields related to those covered by the work of the Biological Survey, but lying outside of the territory in which the Survey could operate, has provided the material for the better understanding of the mammals of North America in their relationship to those of the world at large.

V

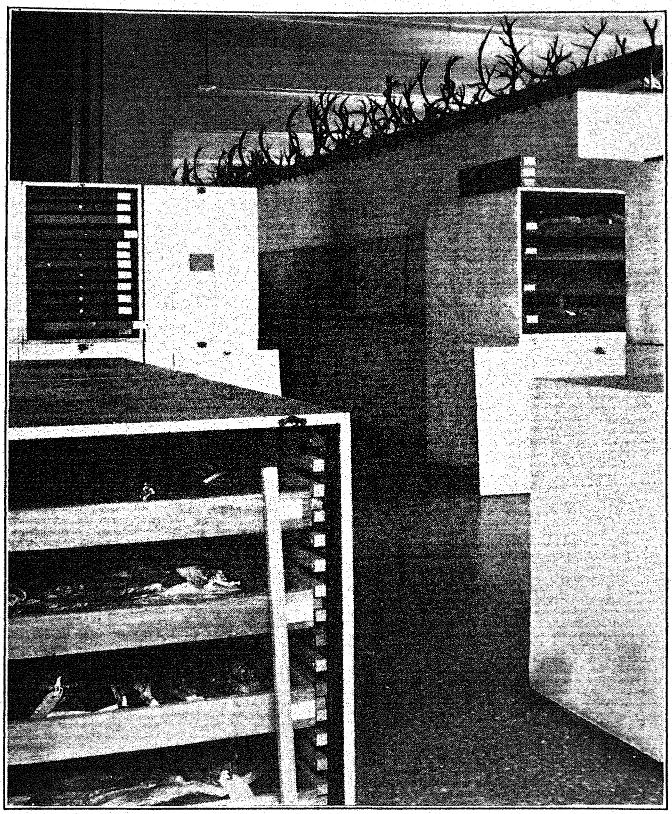
We have now gained a general idea of the relation of mammalogy to human welfare, of what it is, how it is carried on and what the course of its history has been. The question remains: What of its future, particularly as this future concerns the Smithsonian Institution? To obtain its best and most rapid development and to contribute most adequately to the general advance of learning, the study of mammalogy should now be carried on in accordance with definitely thought out plans and in full cooperation with paleontology and physical anthropology, the two branches of research most nearly related to it, branches which would merge with it in an ideal system. This cooperation will in the end become necessary, for the obvious reason that the underlying aim of all three is exactly the same—the acquirement of systematic knowledge about mammals—and an adjustment of results to a common standard must sometime be made. At present we are applying one set of criteria to the study of mammals preserved as skins, skeletons, or pickles, another set to those preserved in rocks, and a third to those with which we come in social contact. As a result the anomalies exist that no attempt to determine the status of the races of men has ever been made by anyone intimately acquainted with modern study of kindred problems in mammals at large, and that the opinions regarding generic, specific, and subspecific distinctions held by workers on fossil mammals are, on the whole, incommensurate with those which are being applied to the study of the living kinds. The standards worked out in the field of mammalogy, in the restricted sense of the word, are the ones which seem likely in the end to prevail, because these standards have been established on the basis of the most complete and varied mass of information,—recent mammals, in the present state of our knowledge, being more numerous and more available for study than their fossil relatives, while man, zoologically speaking, is an insignificant unit in the class to which he belongs. Coordination of effort, in the sense that the workers in these three fields should recognize their common interests and should freely use each other's results, is not only desirable but inevitable. Too strict a division of labor among different museums might, how-

ever, go so far as to eliminate the stimulus of a healthy spirit of competition and thus impede progress instead of advancing it.

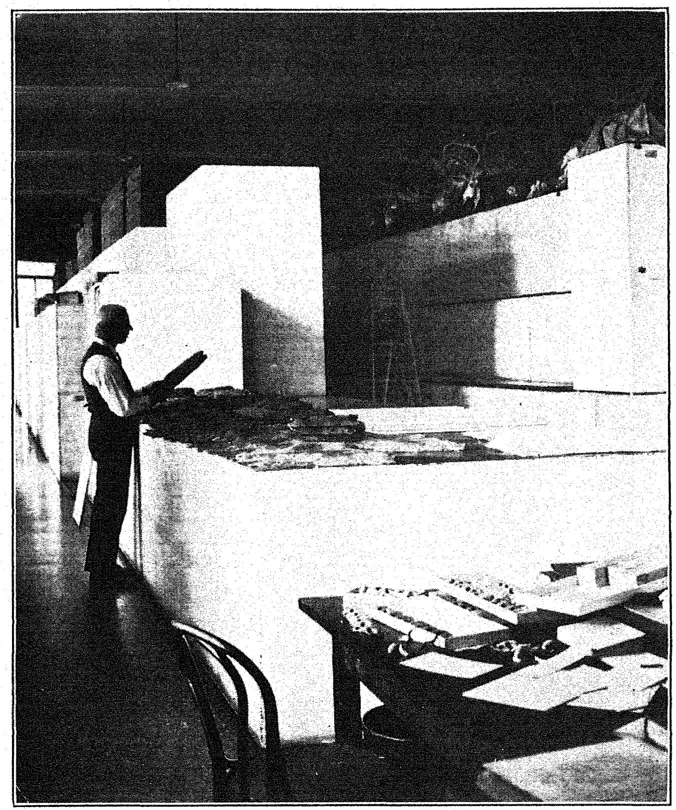
For three decades I have been associated with the Smithsonian Institution as a member of the scientific staff of the National Museum. From this point of view and in this capacity I have witnessed and taken part in the history of the present phase of mammalogy. It is only natural that in closing I should say something about the place which the experience, resources, and men of the Smithsonian qualify the Institution to take in the further development of the study. The Smithsonian Institution is particularly fortunate in its freedom from personal and local ties. It is a private institution, privately founded, privately directed, and privately financed. At the same time the guardianship of the Federal Government gives it security and stability. It is thus able to pursue its own course without regard to immediate economic considerations. The absence of all the duties which pertain to the business of teaching, either in the university sense or in the broader and more popular sense of the educational work now being done by many of our large museums, is a further source of power to the Smithsonian Institution, permitting it to concentrate its efforts on pure research. To make its influence most felt in the future development of mammalogy, the Smithsonian should aim at the establishment of definite lines of activity in particular sections of the field that are not now being sufficiently worked by other agencies, and at a general coordination of the results obtained by investigators throughout the world. And this, if it procures the means, the Institution will do.



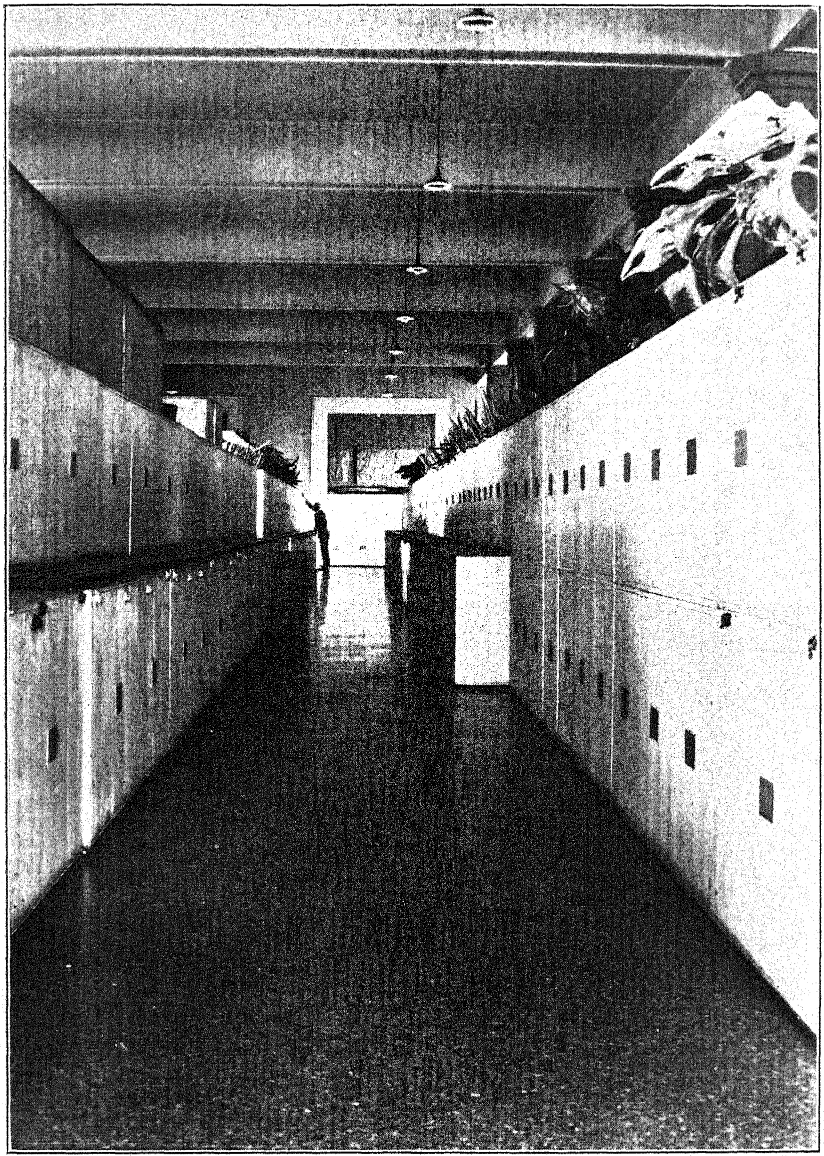
A PART OF THE STUDY COLLECTION OF MAMMALS, U. S. NATIONAL MUSEUM



1. A CORNER IN THE STUDY COLLECTION OF MAMMALS, U. S. NATIONAL MUSEUM



2. AT WORK ON THE STUDY COLLECTION OF MAMMALS, U. S. NATIONAL MUSEUM



A VISTA IN THE STUDY COLLECTION OF MAMMALS, U. S. NATIONAL MUSEUM

NOTE ON THE CONTROVERSY OVER HUMAN "MISSING LINKS"

Few subjects are so interesting as the origin of man. Doctor Miller's painstaking and judicial assemblage of the facts concerning the two sets of fossils which have been most widely discussed in this connection and the diversity of inferences therefrom must merit wide reading. In the author's opinion "we should not hesitate to confess that in place of demonstrable links between man and other mammals we now possess nothing more than some fossils so fragmentary that they are susceptible of being interpreted either as such links or as something else." He adds: "Superficial or prejudiced readers might regard this confession as having an important bearing on the subject of organic evolution in general and of man's origin in particular; but no conclusion could be more unjustified. The idea that all existing plants and animals are derived through some process of orderly change from kinds now extinct is supported by an array of facts too great and too well established to be weakened by doubts cast on alleged family records of any one creature." His outstanding conclusion, in his own words, is this: "The things most needed now are more fossils and many of them." He also remarks: "As the result of 70 years of effort these tireless workers have made exactly two 'finds'—no more. . . ." In such a case how great is the inducement to continue with more adequate means, more exact methods, and more expert selection of localities the search for the earliest relics of the human race!

C. G. Abbot,
Secretary Smithsonian Institution.

THE CONTROVERSY OVER HUMAN "MISSING LINKS"

By Gerrit S. Miller, Jr.
Curator, Division of Mammals, U. S. National Museum

[With five plates]

> The ordinary nonscientific person can not be expected to embrace, and ought not to be expected to embrace, any scientific opinion until it may be asserted of that opinion that the genuine scientific world is fairly unanimous in giving its adherence to it. (Sir Bertram C. A. Windle, Darwin and Darwinism, p. 7, 1912.)

Among recent subjects of animated scientific and popular controversy both in and out of print there is perhaps none that has aroused more widespread interest than the discussion of human "missing links." Is man a creature unconnected with the rest of animate nature? Or is he a direct descendent from ancestors which were not human? And in the latter event can we point to any links which actually connect him with a nonhuman ancestral stock and which

are fairly unanimously accepted by the genuine scientific world as undoubtedly such links? Around these questions as a center the controversy revolves, with no present indication that it is likely soon to come to rest. To some persons the existence of human missing links appears to be more than unlikely; to others it appears to be not only likely but definitely established. Between these two extremes stand those who believe that the links probably existed but that they certainly have not yet been found.

From these points of view writers are tirelessly putting forward their rival opinons. What I wish to undertake here is to summarize these opinions and to set forth the facts which underlie them in such form that the reader may be enabled to come to some conclusion for himself. But before examining any actual fossils it will be necessary to have a clear understanding of the nature and conditions of our problem. I shall therefore begin by explaining what a true missing link is understood to be. Then I shall quote some typical examples of opinions which show how variously the subject can be regarded when the links are supposed to have formed part of a chain binding man's history to that of other mammals. After this a very brief account will be given of the main features which distinguish the skeleton of man from that of the mammals which most nearly resemble him. We shall then be in position to look intelligently at the fossils and at the opinions of the experts who have studied them.

WHAT IS A MISSING LINK?

About the meaning of the term "missing link" there is much popular misunderstanding. Many persons suppose that such a link must have been something in the nature of a hybrid, a monster, or a freak. Nothing could be more incorrect. Whether, as some authorities believe, evolution moves onward by the gradual changing of whole populations of creatures, or whether, as others consider more likely, it moves by a less uniform process in which individual peculiarities play an important part, a missing link can never be anything else than perfectly normal. At the time when it lived there must have been many individuals like it; and the reason why some of the links which have been found in groups of animals not related to man are represented by only one specimen is that fossils, on the whole, are rare.

The idea of the existence of "missing links" arose partly from the discovery of connecting fossils and partly from the commonly accepted theory of organic evolution. According to this the different kinds of living animals and plants have not always existed in the forms that we now see. On the contrary, they have all come to be what they are by a process of "modification of traits from genera-

tion to generation through internal and external factors" (to borrow the words of Dr. David Starr Jordan), a process which has been going on since the beginning of life on the earth. As this process has continued it has led to the production of ever new kinds of plants and animals, which, on the whole, have tended to become more complicated in structure and more perfectly fitted to use the world around them. It follows that at any period of the world's history all the kinds of plants and animals then living are to be regarded as the product of those which lived at earlier periods and that, if all the creatures which ever lived could be passed in review, it would be seen that the distinctions which now separate the different kinds would gradually disappear as we looked farther and farther into the past. This concept has been illustrated by comparison with a flat-topped tree. If we looked at the top only (representing the present), we should be able to see nothing more than a great number of apparently unconnected twigs, but if we examined the lower parts of the tree (representing the past), we should find that the twigs went down and converged into a much smaller number of branches and that these branches in their turn converged into a trunk, which joined all parts into one organic whole. But while we can easily study an actual tree and learn the true relationship of its terminal twigs to each other and to the main trunk, the most that we can do in tracing the genealogy of an animal is to attempt to fit together a few fragments of the tree preserved as fossils. By fitting together these fragments we are able to obtain some indication of the course by which the present-day twigs have grown away from the older branches and these, in their turn, from the main trunk. Men and apes, according to this theory of evolution, are terminal twigs of a single branch, and the "missing links" which we are trying to find are fragments from the lower parts of these twigs near the point where they forked away from the older stem. Human missing links might therefore be creatures of three different kinds—(a) races of men which had not lost all their ape-like peculiarities, (b) races of apes which had begun to take on human characteristics, or (c) races which were neither exactly men nor exactly apes but which combined the characteristics of both.

If a human "missing link" is to be found at all, it must be sought among the fossil remains of mammals long ago extinct, since there is no living animal known which possesses the required peculiarities. Investigators know this, and they have long been diligently searching in rocks and caves, in gravel pits, and stream beds. As the result of 70 years of effort these tireless workers have made exactly two "finds"—no more—which are of such a nature that they can be seriously regarded as furnishing the looked-for direct evidence

of man's blood relationship with animals resembling in some general manner the present-day gorilla and chimpanzee. These two "finds" are known, respectively, from the places where they were unearthed, as the "Java ape man" or "Trinil man" (*Pithecanthropus erectus* Dubois), and the "Piltdown dawn man" (*Eoanthropus dawsoni* Smith Woodward). The former was discovered in 1891–92 near Trinil, central Java, the latter about 20 years afterward at Piltdown, Sussex, England.

WHAT IS THE CONTROVERSY?

So long as the discussion of missing links is limited to extinct creatures which may have served to connect modern one-toed horses with ancient five-toed ancestors or to connect straight shelled "thunderstones" with spirally coiled ammonites it arouses no particular animosity. But when it extends to fossils which can be brought forward as evidence that man is related to something simian, the case is very different. Then it leads to the expressing of opinions delivered from sharply defined and diametrically opposed points of view. In other words, the subject becomes controversial, as may be readily seen from a few especially characteristic and interesting passages which I have selected from the abundant literature.

First I shall take up the writings of authors who do not believe in evolution as applied to man. To them the search naturally appears foredoomed to failure. Sir Bertram C. A. Windle has admirably expressed this mental attitude on pages 26 and 27 of the pamphlet from which I have taken the sentence serving as a motto to this article.

> Then, in the next place, there is the question of the missing link or links. "There is not, as is often assumed, one 'missing link' to be discovered, but at least a score of such links, to fill adequately the gap between man and apes; and their nondiscovery is now one of the strongest proofs of the imperfection of the geological record." (Wallace, The World of Life, 1911, p. 247.) What an amazing *non-sequitur*! Surely it might be claimed, with at least equal justice, that the fact that the "missing links" have not turned up is some sort of proof that they do not exist, at least in any quantity. See the force of a *parti pris!* The venerable writer of the lines just quoted has in a paragraph almost immediately preceding stated that "all evolutionists are satisfied that the common ancestor of man and the anthropoid apes *must* [his italics] date back to the Miocene, if not to the Eocene, period." So that the line of argument is this: Although no one has ever seen any trace of him, man and the apes must have had a common ancestor at the time mentioned; nothing has ever been found of that ancestor; therefore the geological record is imperfect. It does not need any profound acquaintance with logic to see through that syllogism.
>
> At any rate, Wallace admits that there are a number of missing links, and Branco, who as director of the Geological and Palaeontological Institute of the Berlin University, may be accepted as a competent authority, tells us that in

the history of our planet man appears as a genuine *Homo novus*. It is possible, he says, to trace the ancestry of most of our present mammals among the fossils of the Tertiary period, but man appears suddenly in the Quaternary period, and has no Tertiary ancestors as far as we know. Human remains of the Tertiary period have not yet been discovered, and the traces of human activity, which have been referred to that period, are of a very doubtful nature, but Diluvial remains abound. Man of the Diluvial epoch, however, appears at once as a complete *Homo sapiens*. And further to the question, "Who was the ancestor of man?" he replies, "Palaeontology tells us nothing of the subject—it knows no ancestors of man."

The same train of thought is carried on by Erich Wasmann, in his Modern Biology and the Theory of Evolution. (Translated by A. M. Buchanan from the third German edition; St. Louis, 1923.)

What answer does palaeontology make to our question [with regard to the ancestry of man]? She does not merely say "The missing link between man and ape has not yet been discovered." . . . But palaeontology tells us far more than this and, relying on the results of most recent investigations, she says: "We have the pedigree of the present apes, a pedigree very rich in species and coming down from the hypothetical ancestral form of the oldest Tertiary period to the present day. Zittel's "Grundzüge der Paläontologie" gives a list of no fewer than 30 genera of fossil Pro-simiae and 18 genera of fossil apes, the remains of which are buried in the various strata from the Lower Eocene to the close of the Alluvial epoch, but not one connecting link has been found between their hypothetical ancestral form and man of the present time. *The whole hypothetical pedigree of man is not supported by a single fossil genus or a single fossil species.*"

How extraordinary! If man were really descended from a prehistoric ancestor, common to him and to the apes of the present day, there must surely be some fossil trace left of his branch of the genealogical tree and not only traces of the branch leading to apes!

I should like to commend this scientific truth to the serious consideration of all those who regard the descent of man from beasts as actually proved or who hope that it will be actually proved in the near future. As a critical student of nature, I am bound to express my fears that the upholders of this theory will find themselves disappointed.

Coming to thoroughgoing evolutionists, we find that many of them believe that human missing links have been demonstrably discovered. This opinion is set forth in no unfaltering words by Sir Arthur Keith in his presidential address before the British Association for the Advancement of Science given at Leeds, August 31, 1927.[1] He says:

We now know, that as Darwin sat in his study at Down, there lay hidden at Piltdown, in Sussex, not 30 miles distant from him, sealed up in a bed of gravel, a fossil human skull and jaw. In 1912, 30 years after Darwin's death, Mr. Charles Dawson discovered this skull and my friend Sir Arthur Smith Woodward described it, and rightly recognized that skull and jaw were parts of the same individual and that this individual had lived, as was determined by geological and other evidence, in the opening phase of the

[1] Printed in Science, n. s. vol. 66, pp. 201–208, Sept. 2, 1927, and in Nature, vol. 120, suppl., pp. 14–21, Sept. 3, 1927.

Pleistocene period. We may confidently presume that this individual was representative of the people who inhabited England at this remote date. The skull, although deeply mineralized and thick-walled, might well have been the rude forerunner of a modern skull, but the lower jaw was so apelike that some experts denied that it went with the human fossil skull at all, and supposed it to be the lower jaw of some extinct kind of chimpanzee. This mistake would never have been made if those concerned had studied the comparative anatomy of anthropoid apes. Such a study would have prepared them to meet with the discordances of evolution. The same irregularity in the progression of parts is evident in the anatomy of *Pithecanthropus*, the oldest and most primitive form of humanity so far discovered. The thigh bone might easily be that of modern man, the skull cap that of an ape, but the brain within that cap, as we now know, had passed well beyond an anthropoid status. If merely a lower jaw had been found at Piltdown, an ancient Englishman would have been wrongly labeled "Higher anthropoid ape"; if only the thigh bone of *Pithecanthropus* had come to light in Java, then an ancient Javanese, almost deserving the title of anthropoid, would have passed muster as a man (p. 204). . . . In a brief hour I have attempted to answer a question of momentous importance to all of us—What is man's origin? Was Darwin right when he said that man, under the action of biological forces which can be observed and measured, has been raised from a place amongst anthropoid apes to that which he now occupies? The answer is yes! and in returning this verdict I speak but as foreman of the jury—a jury which has been empaneled from men who have devoted a lifetime to weighing the evidence. To the best of my ability I have avoided, in laying before you the evidence on which our verdict was found, the rôle of special pleader, being content to follow Darwin's own example—Let the truth speak for itself (pp. 207–208).

No less convinced of our positive knowledge is Prof. Henry F. Osborn. His opinion, however, differs from the one expressed by Sir Arthur Keith in a very important detail. According to Keith and many other students, the line of human ancestry goes back to creatures which would be recognized, if found, as members of the same family as the living gorilla and chimpanzee. According to Osborn such is not the case. He has clearly stated his views in a paper entitled "Dawn-Man Appears as Our First Ancestor," published in the New York Times, Sunday, January 9, 1927, section XX, page 3.

I assign the Trinil man of Java, through my collateral researches, as of the very dawn of the Age of Man, or Quaternary. Thus on the very threshold of the Age of Man stand the two greatest achievements of prehistoric discovery,—namely, the Trinil man of Java and the Piltdown man of Sussex, England. The latter, aptly termed *Eoanthropus* (signifying "dawn man") by Dr. Arthur Smith Woodward, F. R. S., has a brain so distinctively human that the best anatomical authority places it very close indeed to the lower types of the existing human brain. The degree of brain-power intelligence of the Trinil man is therefore of the utmost concern: Is his brain power of the same kind, perhaps a little better, than that of an ape, a chimpanzee, or a gorilla, or is it far superior to that of an ape and similar to that of a lowly order of man? We have recently found the answer. . . . Dr. Frederick Tilney has been studying the psychology of the Trinil man through the evi-

dence revealed in a cast of the brain, which demonstrates beyond a doubt that the scientific name *Pithecanthropus* applied by Dubois is a misnomer, that the so-called *Pithecanthropus* was not an "ape man," as the Greek word implies, but a true "pro-man" or "dawn man." . . .

I am glad to be the first to befriend the dawn man from the long pre-Stone Age and to remove from his reputation the bar sinister of ape descent. . . . The myth of ape ancestry lingers on the stage, in the movies, in certain antinaturalistic literature, in caricature of our pedigree, even in certain scientific parlance, but the ape-ancestry hypothesis is entirely out of date and its place is taken by the recent demonstration that we are descended from "dawn men," not from "ape-men." The crucial point in this demonstration is the application of modern intelligence tests to the Trinil man of Java through the expert observations of my Columbia colleagues, Prof. J. Howard McGregor, anatomist, and Prof. Frederick Tilney, psychiatrist.

The Trinil man is a dawn man and not an ape man. He walked erect, he thought as man, he probably spoke as a man, although his vocabulary was limited. . . . But in the dawn man was the potency of modern civilization. A welcome gift from anthropology to humanity is this banishment of the myth and bogie of our ape ancestry.

Other convinced evolutionists take a different stand. They fully believe, for a variety of reasons, that man owes his present structure to a long and gradual process of development away from nonhuman ancestors, but they contend that we have not yet discovered fossils which furnish direct evidence of this process. Prof. Martin Ramström, in a paper published 10 years ago in the bulletin of the Geological Institution of the University of Upsala (vol. 16, pp. 261–304, November 22, 1919), clearly expounded this view. His conclusions I translate as follows:

Theories and working hypotheses are clearly necessary in scientific work. But it seems to me not entirely right to "reconstruct" *unknown* links in the chain of evolution according to these hypotheses and then to lay such a "restoration" before the public in the literature and in museums. Without more certain premises and foundations palæontology and anthropology become a veritable land of Babel—everything becomes unsteady! After a few years perhaps another investigator follows this same method of "reconstruction." He perhaps substitutes a contradictory opinion and discovers in his turn a "proof" to support his way of thinking. And which of the two is right?

Let me give just two examples: *Pithecanthropus* and *Eoanthropus*. Eugene Dubois' find, made in a river bed and put together out of a mixture of fossil bones, consisted of—

An *apelike* skullcap;
Several *apelike* teeth;
A *manlike* thigh bone.

Out of this was put together the transition form *Pithecanthropus* (Haecket). And it was accepted by many as a proof of the theory that in the process of human development the upright gait was the primary factor and the high specialization of the brain was a secondary phenomenon. Literally the reasoning was as follows: "The fact that the femur appears relatively more manlike than the skull merely confirms the idea (auffassung), supported from several directions, that in the morphogenetic transition from apes to men the adop-

tion of the upright walking attitude led the way. . . . (Zeitschr. für Ethnologie, 1905, p. 748.) That was the idea about 15 years ago.

Now: *Eoanthropus dawsoni*, likewise an assembled river-bed find, includes—

A *human* brain case;
Some "*human*" teeth;
An *apelike* lower jaw.

Thus an antithesis to *Pithecanthropus*. And at present *Eoanthropus* is taken as the support for another idea about the course of human evolution. The deduction at present is as follows: "So far from being an impossible combination of characters, this association of brain and simian features is precisely what I anticipated in my address . . . some months before I knew of the existence of the Piltdown skull, when I argued that in the evolution of man *the development of the brain must have led the way*. The growth in intelligence and in the powers of discrimination no doubt led to a definite cultivation of the æsthetic sense which, operating through sexual selection, brought about a gradual refinement of features." (Nature, vol. 92, October 2, 1913, p. 131.)

Therefore, according to *Pithecanthropus*, the upright gait is the primary element in the process by which man has come to be man.

According to *Eoanthropus* the development of the brain is the primary element.

Who is right? Who stands on firm ground? Where are the definite proofs?

As to our conduct toward the public I wish in closing to call attention to the memorable words of Professor Boule (L'Anthropologie, 1915, p. 184). Concerning certain reconstructions of fossil men he says: "Our duty is to protest. For such attempts, however agreeable they may appear in certain respects, are of a nature to throw discredit on a science which is still having so much difficulty in getting official recognition and which does not deserve to be thus travestied."

Coming back to the subject two years later in a special article on the Trinil "find" (Der Java-Trinil-Fund, Upsala Läkareförenings Förhandlingar, n. s., vol. 26, Festskr. Prof. J. Aug. Hammar, art. 29, pp. 1–37, 1921), Professor Ramström continued:

The fossils were much scattered about, and it was not at all because of their proximity of deposition that Dubois put together as parts of one individual the apelike skullcap and the manlike thigh bone. The latter was widely separated from the former, lying 15 meters (50 feet) farther upstream and nearer to the present river bed. As we can see from his original report, he was led into this course because E. Haeckel, in the anthropogenetic system published in his Natürliche Schöpfungsgeschichte, had set up a hypothetical creature "which walked erect and had a higher intellectual development than the anthropoids, but was still unable to speak," and had given it the name "Pithecanthropus." And when Dubois discovered the skullcap and the femur he thought he had found the "manlike mammal which clearly forms such a link between man and his nearest known mammalian relatives as the theory of development supposes." And further he says "*Pithecanthropus erectus* is the transition form which in accordance with the teachings of evolution must have existed between men and the anthropoids. He is the ancestor of man."

It follows that *the Haeckelian theory of human evolution became the motive which caused Dubois to put the Trinil fossils together as an individual of the transition type.*

The three points of view should now be easy to understand.

First. Missing links can not be expected to exist.

Second. Missing links have been found; beliefs that they have not arise from ignorance.

Third. Missing links have not been found; beliefs that they have arise from preconceptions.

IS ANY AGREEMENT POSSIBLE?

To the question whether or not reconciliation is possible among men whose opinions differ so radically the only answer seems to be that nothing can bring agreement short of the discovery of evidence so convincing as to compel its general acceptance by the scientific world.

What would be the nature of such evidence? As we can not hope to find anything more than the skeleton of a missing link, the evidence would be furnished by the structure of the bones and teeth. To weigh such evidence it is necessary to know something of the essential features which distinguish the skeleton of man from that of monkeys and apes. These features are all related to the two chief physical peculiarities of man—namely, the upright position of the body and the large size and unusually great weight of the brain. The upright position has set its stamp most conspicuously on three parts of the skeleton—the foot, the pelvis, and the base of the skull; the large brain has set its stamp on the size and shape of the upper and posterior part of the skull. Man's foot is characterized by its ability to act as the habitual support for the entire weight of the body and its inability to grasp in the manner of a hand, features which are particularly indicated by the bones of the heel and of the great toe. His pelvis differs from that of the apes in its bowl-like form suited to holding the superimposed viscera. The base of his skull is so constructed that the points of support are approximately beneath the center of gravity, and the whole mass of the head can thus be balanced on the top of the upright vertebral column, something which can not happen in any monkey or ape. Finally, man's brain case is greatly swollen in proportion to the size of his face and jaws. Less fundamental peculiarities may be found in the curved form of the human lower jaw, in the shape and size of the teeth, in the structure of the bones in the leg, and in the general lengthening of the leg and shortening of the arm. Apes and monkeys, in contrast to man, habitually walk on all fours when on the ground; their feet are so constructed that they are as good grasping organs as their hands; the weight of the viscera, when the animals are walking, is mostly slung beneath the horizontal backbone and not mostly piled upon the pelvis; the supports

for their skulls are situated behind the center of gravity, so that the head has to be constantly held in position by powerful muscles; finally, the facial part of their skulls is relatively large and their brain cases are relatively small.

Properly to qualify as a "missing link," a "find" would have to show that it was part of a creature which had some of the essential characteristics of both humans and apes. It would not be necessary that all parts should be intermediate to exactly the same degree, for, as Sir Arthur Keith very properly points out, evolution has its discordancies, and in the course of racial development one organ commonly alters its structure at a different rate from another. But there are two requisites which could not be dispensed with— first that more than one part of the animal should be discovered, and second, that these parts should have unquestionably belonged together. Why this is necessary may need explaining. Fossil skeletons are sometimes found with the bones practically undisturbed, or, if somewhat scattered, all clearly of one kind with no admixture of any other sorts. On the other hand, they may be found jumbled together in what were once quicksands, pits, or crevices where animals of several kinds have perished, or in what were once stream beds where loose bones of many sorts have been irregularly spread or collected by the action of the water. When the bones of a fossil skeleton retain their original position in the body of the animal the evidence is clear; when they have become widely separated, and particularly when they have been mixed with remains of other creatures, the evidence is perplexing. The reason why more than one part of the supposed link must be known is this—namely, that one part of an animal not infrequently resembles the corresponding part of another to which it is not nearly related. This likeness without relationship is usually called "parallelism" or "convergence," and it is so common throughout nature that everyone who is occupied with the classification of animals must be constantly ready to take it into account. The similarities in general form between a porpoise and a fish or between a snake and an eel are well-known examples of parallelism. In their fundamental structure the animals of each pair are profoundly different; but in their external form they are remarkably alike. On the other hand, there are often found striking resemblances between particular parts of two animals which are unlike in general form. For instance, the crowns of the molar teeth in one of the extinct North American peccaries deceptively resemble the crowns of human molars, as has recently been brought out during

the discussion of the case of the famous "*Hesperopithecus*".[2] The shape of the skull and teeth in a marsupial from Australia and a lemur from Madagascar is rodentlike, while in the rest of the body both animals are very different from rodents. Parachute membranes of almost identical structure have been developed by mammals of four widely unrelated kinds. It follows, therefore, first that a single tooth, bone, or fragment of a fossil bone which resembles the corresponding part of the human skeleton does not necessarily pertain to a creature nearly related to man, and second, that even if such a single fragment were exactly intermediate in structure between the corresponding part of man and of some particular kind of great ape it would not furnish evidence of the existence of an animal *whose total structure was similarly intermediate.* The only conclusion that could be safely drawn from a single bone or tooth is this:—That the specimen illustrates a stage of structural intermediateness, but this stage might have been arrived at as readily without direct blood relationship as with it. A good example of what I mean is furnished by the molar teeth of man, chimpanzee, and gorilla. In their structure the molars of the chimpanzee are intermediate between those of gorilla and man, but every one knows that a chimpanzee is not a "link" either missing or living; yet the characters of the teeth are such that, if the chimpanzee were extinct and some of its molars were the only known fragments of any fossil ape, the unearthing of these teeth might easily be hailed as the discovery of a missing link.

With these circumstances in mind, it should be clear, I think, that in order to bring the genuine scientific world into fairly unanimous agreement it would be necessary to lay before it two or more parts of a missing link, and that these parts should not only give trustworthy information about the structures most characteristic of man but they should also have been found under circumstances showing that they pertained to one individual. There is nothing special about this criterion. It is the one used in the study of all fossils pertaining to animals other than man.

In the light of the understanding which we have now gained, what is the status of the two fossils which have caused so much controversy? I wish to leave to the reader the pleasure of finding his own answer to this question. My part will be to summarize what is actually known about the "Java Man" and the "Piltdown Man" and to give an outline of what has been written about them.

[2] See Osborn, Amer. Mus. Novitates, No. 37, pp. 1–5, figs. 1–3, Apr. 25, 1922; Gregory and Hellman, Amer. Mus. Novitates, No. 53, pp. 1–16, figs. 1–6, Jan. 9, 1923; Gregory, Science, n. s., vol. 66, pp. 579–581, Dec. 16, 1927.

THE JAVA APE MAN OR TRINIL MAN

(*Pithecanthropus erectus* Dubois)

This "find" consists of a skullcap, a femur, and two lower molar teeth. The specimens are represented in Plates 1, 2, and 3, and Plate 4, Figure 2. A third tooth, a lower premolar, has also been described, but it has not figured conspicuously in the discussion.

Dr. Eugene Dubois, to whom the discovery is due, thus describes the circumstances:

For the proper interpretation of these osseous remains the circumstances under which they were found is quite as important a factor as the anatomical considerations. I will therefore first give some particulars regarding their situation when discovered. . . . At the place where the remains were discovered at Trinil the strata, everywhere composed of volcanic tufa, lie exposed in the clifflike declivity of the bank of a river of considerable size, the Bengawan, or Solo. They usually consist here of a sandstone of slight consistency which, in its deeper layers at about the level of the river during the dry season, becomes coarser and coarser as more and more lapilli or volcanic stones form part of its composition. The bones are found throughout the entire thickness of the sandstone strata, being very numerous in the lower half and most so in the stratum, about 1 meter thick, in which the lapilli are found. In the conglomerate which lies under this I found but few, and none at all in the subadjacent argillaceous layer. The four fragments of the skeleton of *Pithecanthropus* were found in different years, because, on account of the rise of the river during every rainy season, the excavations were necessarily suspended and could not be resumed until the next dry season. Besides, in the same working season one fragment was found later than the other, because the stone had to be removed cautiously in layers and by marked-off areas. The four fragments were, however, found at exactly the same level in the entirely untouched lapilli stratum. They were therefore deposited at the same time—that is to say, they are of the same age. The teeth were distant from the skull from 1 to, at most, 3 meters; the femur was 15 meters away. The quite sharp relief of their surface does not support the theory that they have been washed out from some older layer and then embedded for a second time. They were found at the place of their original deposit. Besides, they all show exactly the same state of preservation and of petrefaction as do all other bones that have been taken from this particular stratum at Trinil. Their specific gravity (sp. gr. of compact tissue=2.456) is much greater than that of unpetrified bones (sp. gr. of compact tissue=1.930). The femur weighs 1 kilogram, therefore considerably more than double the weight of a recent human femur of the same size; the medullary cavity is partly filled with a stony mass. The eroded upper surface which the skullcap and not the femur shows occurred in the bed where it was found, appearing on many bones excavated near the skullcap, and is caused by infiltration of water through the cliff at that place. Associated with these bones I also found very numerous remains of a small axislike species of *Cervus*, frequently, also, the remains of *Stegodon*. Farther away were found *Bubalus*, apparently identical with the Siwalik species, *Leptobos, Boselaphus, Rhinoceros, Felis, Sus, Hyaena,* that all appear to be of new species. Of species found in other situations of the same stratum I will mention a gigantic *Manis*, more than three times the length of the existing Javanese species; a *Hippopotamus*, belonging to the same

subgenus, *Hexaprotodon*, as the forms from the Siwalik and Narbada strata of western India. Upon the evidence of these remains I determined that the four skeletal fragments were of exactly the same age, and very probably early Pliocene.

The first description of the Java man was published in a pamphlet issued at Batavia, Java, in 1894. Throughout the scientific world it was immediately read and commented on with intense interest by zoologists and anthropologists alike. But the fact soon became apparent that the only point of universal agreement among these readers was their interest; their opinions differed to an astonishing degree. Some accepted the belief of Dubois that the remains came from one individual; others regarded the circumstances of the discovery as giving no support to it. About the skullcap some agreed with Dubois that it clearly represented a transition stage between ape and man; others pronounced it human, and still others were as fully convinced that it was simian. In April, 1896, Dubois gave a summary of the opinions of 19 writers: 5 regarded the skullcap as simian, 7 as human, and 7 as intermediate. Their names are of enough interest to be reproduced here.

Simian	Human	Intermediate
R. Virchow.	W. Turner.	E. Dubois.
W. Krause.	D. J. Cunningham.	L. Manouvrier.
W. Waldeyer.	A. Keith.	O. C. Marsh.
O. Hamann.	R. Lydekker.	E. Haeckel.
H. ten Kate.	Rud. Martin.	A. Nehring.
	P. Matschie.	R. Verneau.
	P. Topinard.	A. Pettit.

The controversy which thus began has not yet ended. So many writers have taken part in it that I shall make no attempt to list them all or to give their views in detail. A summary will suffice. But before presenting this summary, and as the best means for enabling the reader to understand the violently conflicting opinions which he will find in it, I shall quote rather extensively from the chapter entitled "Pithecanthropus—The Ape Man" in Prof. Marcellin Boule's Fossil Men (translated by J. E. and J. Ritchie from the second French edition, 1923).

If we possessed only the skull and the teeth, we should say that we were dealing with a large ape; if we had only the femur, we should declare we were dealing with a man.

A first and important question thus arises: Did the skullcap, the teeth, and the femur, found separately and at more or less considerable intervals of time and distance, belong to the same being? Dubois considered himself justified in asserting that they did, because no remains of large primates have ever been found in Java except in this spot at Trinil, and the simultaneous presence of several species appears very improbable. Further, the various bones were scattered at quite inconsiderable distances from one another. These are certainly good arguments, but they are not conclusive. Some doubt remains, and will

still remain, until new and more fortunate explorations put us in possession of less imperfect remains found in close association.

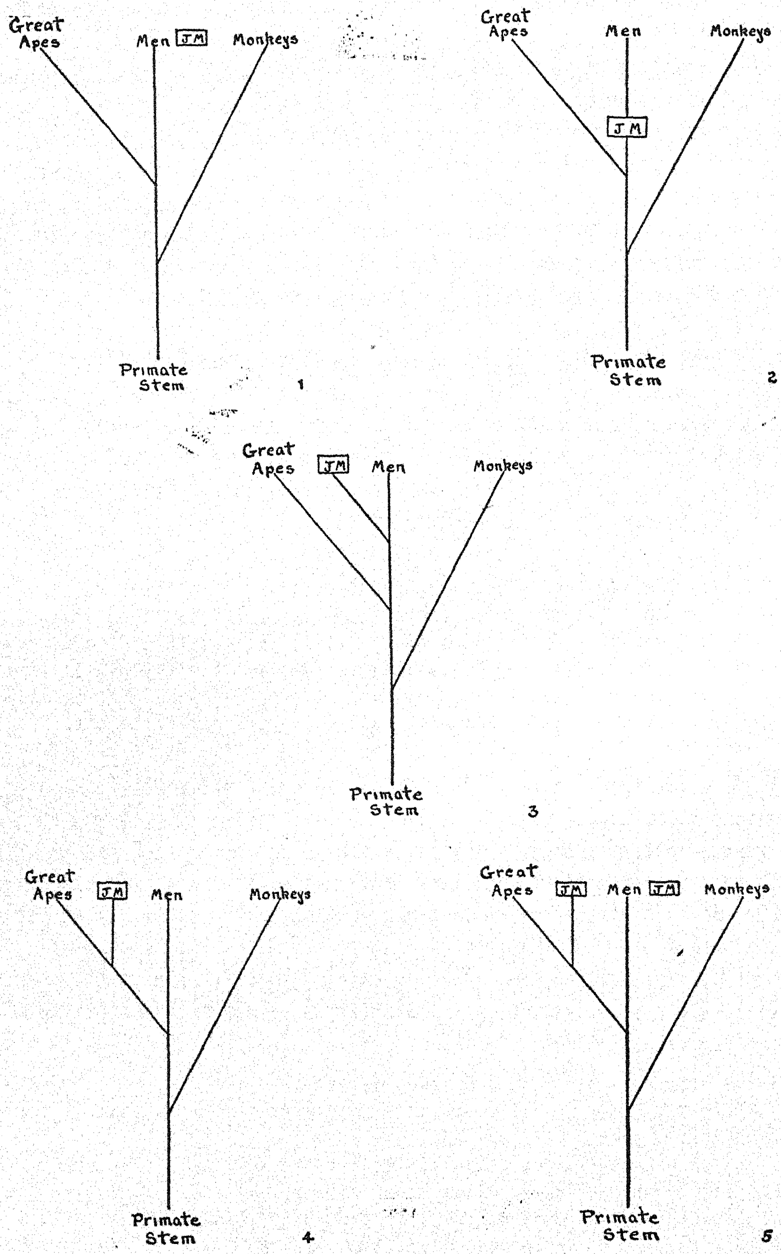


FIGURE 1.—Diagram representing different opinions as the relationships of the Java man, JM

The fact having been taken for granted that the Trinil remains belonged to one and the same creature, attempts at restoration were undertaken. Dubois and Manouvrier published reconstructions of the cranium and even of the whole

skull. These attempts, coming from medical men, and being based principally on human anatomy, are far too hypothethical, since we possess no data for the reconstruction of the base of the skull, the whole face, and all the apparatus of the lower jaw. It is astonishing to find a great palaeontologist like Osborn also publishing attempts of this kind. Dubois ventured still further in the realm of imagination when he exhibited at the International Exhibition of 1900, in the Dutch Indies pavilion, a painted model of *Pithecanthropus* as he appeared in life!

Various interpretations have been given of the facts which I have just summarized as briefly but as accurately as possible. According to many scientists, Dubois' opinion that we have here a transition form between the anthropoid apes and man is justified. Of such, I may mention in France, Manouvrier and Verneau; in America, Marsh and Osborn; in England, Duckworth, Sollas, and Keith; in Australia, Berry and Robertson; in Germany, Nehring, Schwalbe, Haeckel, and others. Other German authors, Virchow, Krause, Waldeyer and Ranke, the Italian Sergi, and the Swiss R. Martin, believe that *Pithecanthropus* was simian in nature. Topinard in France, Houzé in Belgium, Lydekker, Turner, and Cunningham in England, are inclined to regard it as a man.

To consider only the most important relic, the skullcap; unquestionably this falls into place exactly, I might almost say ideally, between that of the large apes, like the chimpanzee, and of a man of archaic characters, such as the Neanderthal man.

But it must be distinctly stated, and in this case repeated, that resemblance does not always imply descent. Even if, in the sum of his known characters (poor at the best), *Pithecanthropus* actually forms a structural link between the large apes and man, it does not necessarily follow that he must be regarded as a genealogical link, and this distinction is not, as has been asserted, merely a question of words.

In order to come to a decisive conclusion regarding his true genealogical relationships, we should require to possess at least the complete skull and lower jawbone of *Pithecanthropus;* for all the reconstructions, with their more or less marked anthropomorphism, which have been advanced by different authors, will never help to solve the problem. In the present state of our knowledge, I do not think that we are yet in a position to believe that there was any direct descent between *Pithecanthropus* and man, such as the genealogical tree prepared by Dubois would indicate. [Figure 1, diagram 2.]

It is certainly more satisfactory to admit that the evolutionary branch to which the famous Javan fossil belongs was different from the human branch. Naturalists have no longer any doubt that we are related to the apes; but it is of some interest to try to define this relationship, especially when we meet with a creature apparently more akin to us than any other. Dubois rightly pointed out that if *Pithecanthropus* is, so to speak, only our granduncle instead of our grandfather, he is none the less an ape man representing a stage in human descent. The majority of scientists to-day adhere to this view. They consider *Pithecanthropus* to be an extinct lateral twig of the human branch. As such he is regarded by Keith, Gregory, and Osborn. [Figure 1, diagram 3.]

It is possible, however, to interpret these genealogical relationships in yet another way. Following Dubois, several naturalists have laid stress on the resemblance between the *Pithecanthropus* remains and the corresponding portions of a gibbon's skeleton. In that case, why not assume that *Pithecanthropus* represents a large form, a giant ape, related to the gibbon group?

still remain, until new and more fortunate explorations put us in possession of less imperfect remains found in close association.

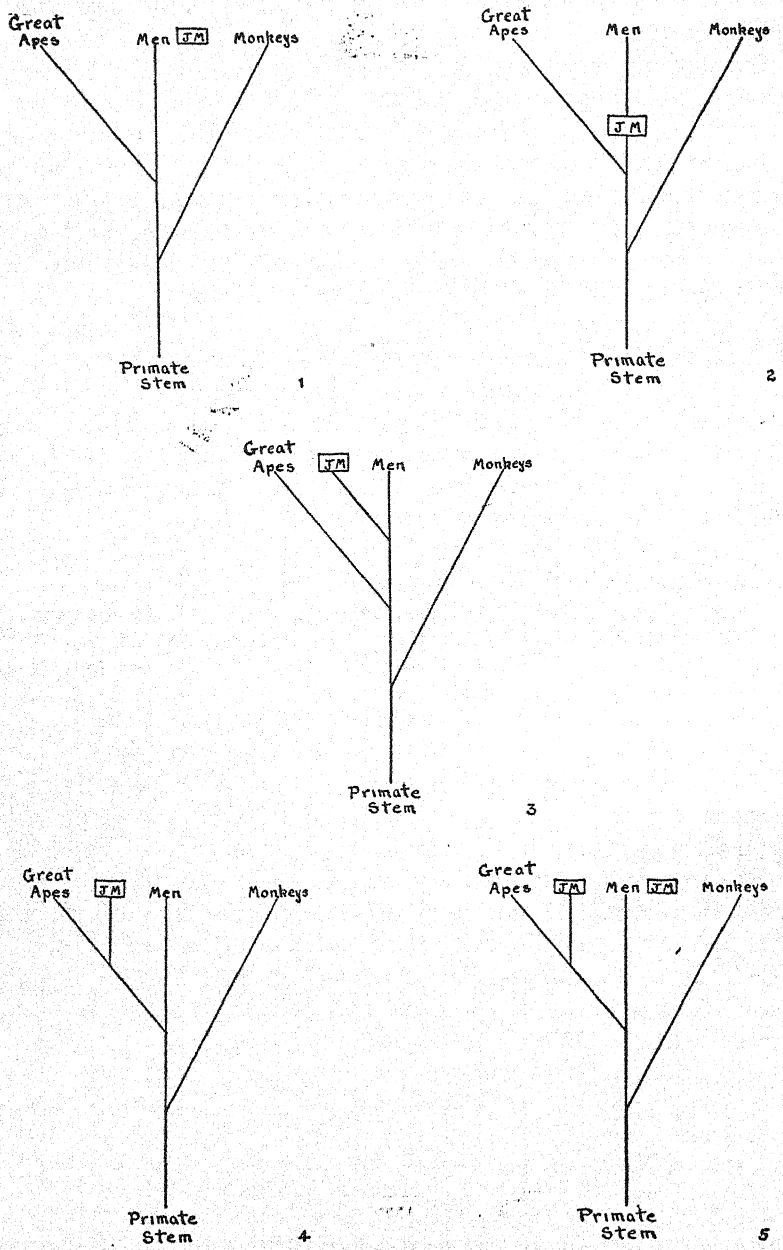


FIGURE 1.—Diagram representing different opinions as the relationships of the Java man, JM

The fact having been taken for granted that the Trinil remains belonged to one and the same creature, attempts at restoration were undertaken. Dubois and Manouvrier published reconstructions of the cranium and even of the whole

skull. These attempts, coming from medical men, and being based principally on human anatomy, are far too hypothethical, since we possess no data for the reconstruction of the base of the skull, the whole face, and all the apparatus of the lower jaw. It is astonishing to find a great palaeontologist like Osborn also publishing attempts of this kind. Dubois ventured still further in the realm of imagination when he exhibited at the International Exhibition of 1900, in the Dutch Indies pavilion, a painted model of *Pithecanthropus* as he appeared in life!

Various interpretations have been given of the facts which I have just summarized as briefly but as accurately as possible. According to many scientists, Dubois' opinion that we have here a transition form between the anthropoid apes and man is justified. Of such, I may mention in France, Manouvrier and Verneau; in America, Marsh and Osborn; in England, Duckworth, Sollas, and Keith; in Australia, Berry and Robertson; in Germany, Nehring, Schwalbe, Haeckel, and others. Other German authors, Virchow, Krause, Waldeyer and Ranke, the Italian Sergi, and the Swiss R. Martin, believe that *Pithecanthropus* was simian in nature. Topinard in France, Houzé in Belgium, Lydekker, Turner, and Cunningham in England, are inclined to regard it as a man.

To consider only the most important relic, the skullcap; unquestionably this falls into place exactly, I might almost say ideally, between that of the large apes, like the chimpanzee, and of a man of archaic characters, such as the Neanderthal man.

But it must be distinctly stated, and in this case repeated, that resemblance does not always imply descent. Even if, in the sum of his known characters (poor at the best), *Pithecanthropus* actually forms a structural link between the large apes and man, it does not necessarily follow that he must be regarded as a genealogical link, and this distinction is not, as has been asserted, merely a question of words.

In order to come to a decisive conclusion regarding his true genealogical relationships, we should require to possess at least the complete skull and lower jawbone of *Pithecanthropus;* for all the reconstructions, with their more or less marked anthropomorphism, which have been advanced by different authors, will never help to solve the problem. In the present state of our knowledge, I do not think that we are yet in a position to believe that there was any direct descent between *Pithecanthropus* and man, such as the genealogical tree prepared by Dubois would indicate. [Figure 1, diagram 2.]

It is certainly more satisfactory to admit that the evolutionary branch to which the famous Javan fossil belongs was different from the human branch. Naturalists have no longer any doubt that we are related to the apes; but it is of some interest to try to define this relationship, especially when we meet with a creature apparently more akin to us than any other. Dubois rightly pointed out that if *Pithecanthropus* is, so to speak, only our granduncle instead of our grandfather, he is none the less an ape man representing a stage in human descent. The majority of scientists to-day adhere to this view. They consider *Pithecanthropus* to be an extinct lateral twig of the human branch. As such he is regarded by Keith, Gregory, and Osborn. [Figure 1, diagram 3.]

It is possible, however, to interpret these genealogical relationships in yet another way. Following Dubois, several naturalists have laid stress on the resemblance between the *Pithecanthropus* remains and the corresponding portions of a gibbon's skeleton. In that case, why not assume that *Pithecanthropus* represents a large form, a giant ape, related to the gibbon group?

This hypothesis is not new; it was clearly stated by several naturalists, particularly by Volz. The bone fragments are in its favor; the most recent geological studies, tending to postdate the layer, also support it. The new argument which I think I can bring forward in its favor is that we know several examples of comparative cases.

In all countries during Pliocene and Quaternary times there were giant forms of animals whose living representatives are now greatly reduced in size. In addition to the great edentates of South America, *Megatherium* and *Glyptodon,* which Cuvier named "giant sloths" and "armadillos," to the enormous Australian marsupial, *Diprotodon,* to a giant Pangolin found in Java in the same layer as *Pithecanthropus,* to the *Trogontherium* of European Pleistocene deposits, which is really a sort of giant beaver; in addition, also, to the whole series of large running birds of Madagascar and of New Zealand recently extinct, examples among the primates themselves are not wanting.

Pilgrim found in the Siwalik Hills the remains of a monkey which he named *Dryopithecus giganteus. Megaladapis,* of the recent geological formations in Madagascar, is none other than a giant lemur. *Archaeolemur* and *Hadropithecus,* from the same layers, are also lemurs of larger size than the living forms; but they show morphological characters of a higher order, denoting a tendency toward the higher ape type, for the tendency toward greater perfection is not exclusively confined to the human branch.

We may therefore consider that *Pithecanthropus,* discovered in the same zoological region as the modern gibbons, may have been a large species either of the genus *Gibbon,* or rather of a closely allied genus related to the same group. This form might have been superior to its congeners, not only in size but also in other morphological characters, and particularly in cerebral capacity, a character of the first importance in which *Pithecanthropus* truly approaches the human stock. . . . It would thus represent a branchlet, more highly specialized than the neighboring branchlets of the most highly developed gibbon branch, and it must soon have died out, perhaps because of this very specialization. *Pithecanthropus,* then, does not belong to the ancestral line of the genus *Homo.* The more or less "human" characters of its skullcap, and even of its femur, can only be looked upon as characters due to convergence and not to descent. [Figure 1, diagram 4.]

This interpretation of the memorable Javan discovery does not lessen its interest. I am tempted to say that, on the contrary, it increases it, since the human line, while still retaining its independence, seems thus morphologically less isolated than formerly from the neighboring lines. It leads us to the admission that in other days there existed anthropoids higher than living anthropoids, but inferior to the fossil men known to us, who themselves were inferior to living man. The physical relationship between ape and man here asserts itself from a new point of view.

SUMMARY OF OPINIONS ABOUT THE JAVA MAN

(*Pithecanthropus*)

There is only one point on which all writers agree, namely, that the skullcap is strangely different from the corresponding part of other known mammals, both recent and fossil. In striking contrast we find that there are not less than 15 points of disagreement.

(1)

The deposits in which the fossils were found are of Tertiary age (lower to upper Pliocene, therefore old enough to be reasonably expected to contain remains of a creature ancestral to man) (Dubois, Hilber, Marsh).

The deposits in which the fossils were found are of Quaternary age (lower to middle Pleistocene, therefore not old enough to be reasonably expected to contain remains of a creature ancestral to man) (Branca, Obermaier, Pervinquière, Ramström, Schuster, Volz).

(2)

The way the bones were deposited in the ancient stream bed counts against the reference of all these parts to one individual (Ramström, Virchow).

The way the skullcap, teeth, and femur were deposited in the ancient stream bed at considerable distances from each other does *not* count against the reference of all these parts to one individual (Branco, Dubois, Jaekel, Marsh).

(3)

The remains came from one animal (Dubois, Nehring, and many others).

The remains did not certainly come from one animal (Matschie).

The remains came from two kinds of animal—teeth and skullcap from a gibbon, and femur from a man (Krause); skullcap and femur from a man, teeth from an orang (Topinard). Diagram 5, p. 426.

The remains came from two or perhaps three kinds of animal—skullcap, one ape *(Pithecanthropus)*; teeth another ape, not yet named; and femur perhaps human (Obermaier).

(4)

The characters of the femur are those of ordinary man (Hepburn, Houzé, Kolbe, Manouvrier, Martin, Turner, Vallois).

The characters of the femur are those of a peculiar man (Hrdlička).

The characters of the femur are those of a gibbon (Kollman, Virchow).

(5)

The size of the femur is too great for the bone to have pertained to the same individual as the skullcap (Virchow).

The size of the femur is *not* too great for the bone to have pertained to the same individual as the skullcap (Nehring).

(6)

The condition of the skullcap shows that the surface of the bone was eaten away by acid after deposition (Dubois).

The condition of the skullcap shows that the surface of the bone could not have been eaten away by acid, but that it must have been worn down by violent stream action along with waterworn pebbles before deposition (Houzé).

[If the skullcap had been subjected to stream action, it probably had a different history from the femur, whose delicate, abnormal, bony outgrowths show no evidence of rough treatment.]

(7)

The characters of the skullcap are predominantly human (Cunningham, Martin, Matschie, Houzé, Turner).

The characters of the skullcap are those of a microcephalous idiot (Lydekker).

The characters of the skullcap are those of a Neanderthal man (Topinard).

The characters of the skullcap are intermediate between those of Neanderthal man and the higher apes (Schwalbe).

The characters of the skullcap are intermediate between those of modern man and the higher apes (Nehring).

The characters of the skullcap are simian but with some features that resemble man (Obermaier).

The characters of the skullcap are those of a gibbon (Krause, Manouvrier).

The characters of the skullcap are *not* those of a gibbon (Schwalbe, Weinert).

The characters of the skullcap are predominantly chimpanzeelike (Eimer, in Branco, Ramström, Virchow).

The characters of the skullcap are *not* predominantly chimpanzee-like (Schwalbe).

(8)

The size of the brain alone is sufficient to show that the animal approached man in structure (Dubois).

The size of the brain alone is *not* sufficient to show that the animal approached man in structure (Ramström).

(9)

The creature was an imbecile (Manouvrier).

The creature was a microcephalous idiot (Lydekker).

The brain structure indicated by the cast of the inner surface of the skullcap shows that the animal might have had some power of speech (Dubois).

The brain structure indicated by the cast of the inner surface of the skullcap shows that the animal probably spoke as a man, although his vocabulary was limited (Osborn).

The brain structure indicated by the cast of the inner surface of the skullcap shows that the animal had actually learned to speak (Tilney).

The brain structure as indicated by the cast of the inner surface of the skullcap gives no positive information about the creature's mental capacities (Symington).

(10)

The fact that the two teeth exhibit different degrees of wear counts against the reference of both to one individual (Krause, Virchow).

The fact that the two teeth exhibit different degrees of wear does *not* count against the reference of both to one individual (Dubois, Pearsall, Virchow, later opinion).

(11)

The unworn condition of the wisdom tooth counts against the association of this tooth with the apparently aged skullcap as parts of one individual (Krause, Martin, Virchow, Waldeyer).

The unworn condition of the wisdom tooth does *not* count against its association with the skullcap (Dubois).

(12)

The character of the teeth are predominantly human (Houzé, Martin).

The characters of the teeth are predominantly simian (Kolbe, Nehring, Obermaier, Virchow).

The characters of the teeth (apart from size) are gibbonlike (Manouvrier).

The characters of the teeth are, with unimportant exceptions, within the limits of variation for the living orang (Miller, Topinard).

The characters of the teeth are not definite enough to permit of exact classification (Luschan, Ramström).

(13)

On the assumption that the remains were all those of one animal:

(*a*) The creature was a true transition form between ape and man (Dames, Dubois, Haeckel, Jaekel, Manouvrier, Weilser). Diagram 2, page 426.

(*b*) The creature was human but with some definitely simian characteristics (Cunningham, Keith).

(*c*) The creature was human *without* definitely simian characteristics (Houzé, Martin, Petit). Diagram 1, page 426.

(*d*) The creature had a structure which removes it from a position of direct human ancestry (Boule).

(*e*) The creature was essentially a gigantic gibbon or gibbonlike ape (Boule, Kollman, Volz). Diagram 4, page 426.

(14)

The assumption that the animal was a gigantic gibbon or gibbon-like ape involves insuperable difficulties (Dubois).

The assumption that the animal was a gigantic gibbon or gibbon-like ape involves *no* insuperable difficulties. It is, moreover, supported by the fact that gigantic forms are known to have existed in many groups of mammals during the Pleistocene and late Pliocene and by the circumstance that bones of a gigantic pangolin were found in the same Trinil deposits (Boule, Branco).

The assumption that the animal is a gigantic gibbon can only be made by persons ignorant of the principles of systematic zoology (Schlosser).

(15)

The large size of the remains counts against their having pertained to a creature ancestral to man (Kollman).

The large size of the remains does *not* count against their having pertained to a creature ancestral to man (all writers who regard *Pithecanthropus* as a transition form).

THE PILTDOWN DAWN MAN

(*Eoanthropus dawsoni* Smith Woodward)

The original " find " consisted of four pieces (reconstructed from nine fragments) of a cranium and an imperfect lower jaw bearing two molar teeth. Afterward a pair of nasal bones and a canine tooth were found and described, while still later two more fragments of skull and a third molar tooth made their appearance. The specimens (except the supplementary skull fragments) are figured in Plate 5, and Plate 4, fig. 1. Mr. Charles Dawson, to whom the first discovery was due, thus describes the circumstances:

Several years ago I was walking along a farm road close to Piltdown Common, Fletching (Sussex), when I noticed that the road had been mended with some peculiar brown flints not usual in the district. On inquiry I was astonished to learn that they were dug from a gravel bed on the farm, and shortly afterwards I visited the place, where two laborers were at work digging the gravel for small repairs to the roads. As this excavation was situated about 4 miles north of the limit where the occurrence of flints overlying the Wealden strata is recorded, I was much interested and made a close examination of the bed. I asked the workmen if they had found bones or other fossils there. As they did not appear to have noticed anything of the sort, I urged them to

preserve anything they might find. Upon one of my subsequent visits to the pit, one of the men handed to me a small portion of an unusually thick human parietal bone. I immediately made a search, but could find nothing more, nor had the men noticed anything else. The bed is full of tabular pieces of ironstone closely resembling this piece of skull in color and thickness, and, although I made many subsequent searches, I could not hear of any further find nor discover anything—in fact, the bed seemed to be quite unfossiliferous. It was not until some years later, in the autumn of 1911, on a visit to the spot, that I picked up, among the rain-washed spoil heaps of the gravel pit, another and larger piece belonging to the frontal region of the same skull, including a portion of the left superciliary ridge. As I had examined a cast of the Heidelberg jaw, it occurred to me that the proportions of this skull were similar to those of that specimen. I accordingly took it to Dr. A. Smith Woodward at the British Museum (Natural History) for comparison and determination. He was immediately impressed with the importance of the discovery, and we decided to employ labor and to make a systematic search among the spoil heaps and gravel as soon as the floods had abated, for the gravel pit is more or less under water during five or six months of the year. We accordingly gave up as much time as we could spare since last spring (1912), and completely turned over and sifted what spoil material remained; we also dug up and sifted such portion of the gravel as had been left undisturbed by the workmen. . . . Considering the amount of material excavated and sifted by us, the specimens discovered were numerically small and localized. Apparently the whole or greater portion of the human skull had been shattered by the workmen, who had thrown away the pieces unnoticed. Of these we recovered from the spoil heaps as many fragments as possible. In a somewhat deeper depression of the undisturbed gravel I found the right half of a human mandible. So far as I could judge, guiding myself by the position of a tree 3 or 4 yards away, the spot was identical with that upon which the men were at work when the first portion of the cranium was found several years ago. Doctor Woodward also dug up a small portion of the occipital bone of the skull from within a yard of the point where the jaw was discovered and at precisely the same level. The jaw appeared to have been broken at the symphysis and abraded, perhaps when it lay fixed in the gravel and before its complete deposition. The fragments of cranium show little or no sign of rolling or other abrasion, save an incision at the back of the parietal, probably caused by a workman's pick. . . . Besides the human remains, we found two small broken pieces of a molar tooth of a rather early Pliocene type of elephant, also a much-rolled cusp of a molar of mastodon, portions of two teeth of hippopotamus, and two molar teeth of a Pleistocene beaver. In the adjacent field to the west, on the surface close to the hedge dividing it from the gravel bed, we found portions of a red deer's antler and the tooth of a Pleistocene horse. These may have been thrown away by the workmen or may have been turned up by a plow which traversed the upper strata of the continuation of this gravel bed. Among the fragments of bone found in the spoil heaps occurred part of a deer's metatarsal, split longitudinally. This bone bears upon its surface certain small cuts and scratches, which appear to have been made by man. All the specimens are highly mineralized with iron oxide.

The first description of the Piltdown dawn man was read by Sir Arthur Smith Woodward at a meeting of the Geological Society of London on December 18, 1912. It was published in the Quarterly Journal of the society. (Vol. 69, pp. 117–151, April 25, 1913.) Regarding the skull and jaw as parts of one individual, the author

concluded that the race which the fossils represented was human, but that it differed more widely from modern man than any race heretofore discovered and that it definitely marked the way by which the line of human ancestry runs back to early anthropoid apes. On page 139 he writes:

Our knowledge of the principles of palaeontology compels us to suppose that the full-grown skull in the ancestral mid-Tertiary apes was of the immature rounded shape just mentioned, although we have not yet been fortunate enough to discover an example, and during the lapse of upper Tertiary time the skull type in the whole race of apes has gradually undergone changes which are more or less exactly recapitulated in the life history of each individual recent ape. Hence it seems reasonable to interpret the Piltdown skull as exhibiting a closer resemblance to the skulls of the truly ancestral mid-Tertiary apes than any fossil human skull hitherto found.

This announcement gave rise to a contest of opinion which is probably unequaled in the history of paleontology. More than 75 writers have taken part in it, and one of them [3] has not hesitated to declare that "the Piltdown jaw is the most startling and significant fossil bone that has ever been brought to light . . . because this jaw and the incomplete skull found with it really and in simple fact furnish a link—a form intermediate between the man and the ape." This may be an extreme view but it indicates something of the enthusiasm which has prevailed and which has brought about the result thus described by Prof. H. F. Osborn in 1921.[4] "Over a few fragments of bone, three teeth, and a portion of the jaw, the wise anatomists of Great Britain, of western Europe, and of the North American continent have expressed opinions of every variety." In reviewing these opinions I shall begin with a summary which I published in 1918:

First phase (1913): The mandible was admitted to be almost precisely that of an ape, with nothing human except the molar teeth, which, however, approached the ape pattern in their well-developed fifth cusp and elongated shape. It was neverthless regarded as having formed part of the same individual as the skull. The animal to which this skull and mandible were supposed to have belonged received the generic name *Eoanthropus*. To the objection that such intimate association of the jaw and skull might not be justified, the reply was made that it could only be said that its [the mandible's] molar teeth were typically human, its muscle markings "such as might be expected," and that it was found in the gravel near the skull. Further arguments in favor of this association were based on the circumstance that such a combination of characters in one individual would accord with previously expressed opinions about the probable history of the skull in man. (Woodward, Quart. Journ. Geol. Soc. London, vol. 69, p. 135, April 25, 1913; Waterston, Quart. Journ., Geol. Soc. London, vol. 69, p. 150, April 25, 1913; Woodward, Brit. Med. Journ., vol. 2 for 1913, p. 762, September 20, 1913; Smith, Nature, vol. 92, p. 131, October 2, 1913; Waterston, Nature, vol. 92, p. 319, November 13, 1913; Keith, The Antiquity of Man, p. 459, 1915.)

---

[3] Sir E. Ray Lankester, Diversions of a Naturalist, p. 284, 1915.

[4] Natural History, vol. 21 (1921), p. 577, February, 1922.

Second phase (1915–16): The characters of both the jaw and the teeth were regarded as not merely in a general way simian, but as definitely those of a chimpanzee. Certain features of the jaw were seen to be out of harmony with the skull, according to the associations of structures observed in all hitherto known primates. In the absence of conclusive evidence to prove that these previously unknown associations of structures had existed in one animal, each set of fragments was referred to the genus which its characters demanded. The name *Eoanthropus* was restricted to the human remains; the chimpanzee represented by the jaw was described as *Pan vetus*. (Miller, 1915; Matthew, 1916; Gregory, June, 1916, and July, 1916; Osborn, 1916.)

Third phase (1917): The jaw has obvious peculiarities which make it human in spite of the fact that it presents many points of likeness to that of a chimpanzee. All supposed disharmony between the jaw and the skull is imaginary. The molar teeth are human; radiographs and other evidence show that they differ conspicuously from the corresponding teeth of all great apes. (Pycraft, 1917, with approval of Woodward, Smith, Keith, Underwood, and Broom.)

The subsequent phases of the controversy have been so varied that they can not be grouped under any single caption.

Miller (1918) has shown that the characteristics relied on by Pycraft to prove that the jaw is human are merely features which men and apes possess in common, and that their presence can not be regarded as proof that the jaw and skull could have pertained to one individual.

English writers have on the whole remained true to Smith Woodward's idea that all parts of the Piltdown find pertain to a single individual which, though human, retains so many ape-like features in the jaw and teeth that it can truly be regarded as a link connecting the human line with the anthropoid stock. One of them, Hunter, has, however, attempted to lessen the difficulties by pointing out that in his opinion "an examination of the cranial fragments in detail shows a greater harmony between the anatomical features of the jaw and cranium than has usually been believed to exist." (See addenda, p. 465.)

In America the original Woodwardian view has been reverted to by Osborn and Gregory and has received additional support from McGregor. On the contrary, Hrdlička regards the association of the jaw with the skull as exceedingly difficult of acceptance. According to him it is not unlikely that each represents a peculiar human type. It is particularly instructive to compare the opinions of Professor Osborn and Doctor Hrdlička, because both men have had the privilege of examining the original specimens in the British Museum. Professor Osborn says (Natural History, vol. 21 (1921), pp. 581–582, 590, February, 1922):

Seeing is believing, and the writer eagerly looked forward to a return to the British Museum after so many years of absence and to the opportunity of examining these precious documents, an opportunity which was most cordially extended to him by Doctor Woodward. After attending on Sunday morning,

July 24, 1921, a most memorable service in Westminster Abbey, a building which enshrines many of the great of all time, the writer repaired to the British Museum in the afternoon to see the remains of the now thoroughly vindicated "dawn man" of Great Britain. From a steel fireproof safe these few precious fragments of one of the original Britons, which had been preserved in this manner from the bombs thrown by German aviators, and which will probably be thus guarded from thieves for all future time, were taken out and placed on the table by Doctor Woodward, so that full and free opportunity was given for the closest comparison and study. At the end of two hours, in which also worked flints and a large implement of cut mastodon thigh bone were examined, the writer was reminded of an opening prayer of college days, attributed to his professor of logic in Princeton University: "Paradoxical as it may appear, O Lord, it is nevertheless true," etc. So the writer felt. Paradoxical as it appears to the comparative anatomists, the chinless Piltdown jaw, shaped exactly like that of a chimpanzee and with its relatively long narrow teeth, does belong with the Piltdown skull, with its relatively flat, well-formed forehead and relatively capacious brain case! . . . In conclusion, the writer desires not only to recant his former doubts as to the association of the jaw with the skull, but to express his admiration of the great achievement of his life-long friend, Arthur Smith Woodward, in making the discovery and in finally establishing beyond question the authenticity of the "dawn man" of Piltdown. We have to be reminded over and over again that nature is full of paradoxes and that the order of the universe is not the human order; that we should always expect the unexpected and be prepared to discover new paradoxes.

Writing in the American Journal of Physical Anthropology (vol. 5, pp. 337, 347, December, 1922), Doctor Hrdlička thus describes the impressions which he received:

During his recent trip to Europe, and thanks to the courtesy of Dr. Smith Woodward, the writer was able to submit the original of the lower jaw of Piltdown to a detailed personal examination. This revealed a number of features which have either not been mentioned as yet or have not been enough accentuated in previous reports, and which throw further and it seems conclusive light upon the mooted question as to the human or nonhuman nature of the specimen.

The first strong impression which the specimen conveys is that of normality, shapeliness, and relative gracility of build rather than massiveness. When, after studying the specimens for a good part of two days, the observer took in hand the thick Piltdown skull, there was a strong feeling of incongruity and lack of relationship, and this feeling only grew on further study. As a rule there exists a marked correlation between the massivity of the skull—particularly if, as in this case, the upper facial parts were involved in the same—and the lower jaw. A finely chiseled mandible of medium or submedium strength belongs as a rule to a skull that is characterized in the same way, and vice versa. To connect the shapely, wholly normal Piltdown jaw with the gross, heavy Piltdown skull into the same individual, seems very difficult. After prolonged handling of both the jaw and the skull there remained in the writer a strong impression that the two may not belong together, or that if they do the case is totally exceptional.

An individual, or even genetic, specific, association of the Piltdown jaw with the massive remains of the two Piltdown skulls is, it may be repeated once more, exceedingly difficult of acceptance. The more the lower jaw is studied and understood the less in harmony it appears with the skulls, and

it is not unlikely that these latter belong to totally different, possibly chronologically younger, human individuals.

The opinion of French authorities has remained in agreement with the early expressed view of Boule that the jaw belonged to an ape and that consequently there is no reason to regard it as a part of the man whose brain case was deposited in the gravel where both were found. Discussing the subject of "Man and the gibbon," Ernest-Robert Lenoir remarks of the Piltdown jaw that this curious bone enjoyed a period of great notoriety, but that since it has been shown to the satisfaction of most naturalists that the fossil is only a remnant of an anthropoid, silence has gradually fallen on this find.

Turning to other European countries we find that the dissociation of the jaw from the skull has been upheld by Ramström in Sweden, Mollison and Schwalbe in Germany, and Giuffrida-Ruggeri in Italy. On the contrary, Kleinschmidt, in Germany, accepts all the fragments as parts of one individual and finds that the cast of the mandible clearly shows the horseshoe-shaped form of the human jaw. An entirely new opinion has been put forward in Italy by Fabio Frassetto. According to him the jaw and skull came from one individual, a human being with an oranglike mandible.

By most writers who do not regard the mandible as human, this bone and its teeth have been compared with the corresponding parts of living great apes. The nearly unanimous conclusion has been that both the bone and the molars possessed the characters which could be looked for in an extinct member of the genus now represented by the African chimpanzees. Support of another view (apparently first suggested by Sera in 1917) has been brought forward by Doctor Hrdlička. He regards the jaw and teeth as those "of either a human precursor or very early man" (Amer. Journ. Phys. Anthrop., vol. 5, p. 346), but he finds in the molars a striking resemblance to the corresponding teeth of extinct apes called *Dryopithecus*, whose fossil remains have been discovered in southern France and southern Germany. After tabulating the measurements of some of the teeth of these extinct apes (Amer. Journ. Phys. Anthrop., vol. 6, p. 214, May, 1923), he says:

The conditions shown in this table are a serious surprise. Here is a line of large apes from ancient western Europe, the lower molars of which, in shape and in one case even in size, resemble more than those of any other group of primates or man the teeth of the Piltdown jaw. What is this? The general resemblance in type and size, as well as the marked difference in relative dimensions of the fossil teeth in question to and from those of man have been brought to our attention by W. Branco [in 1898]; but their remarkable closeness in the relative and in one case also in the absolute dimensions to the teeth of the Piltdown jaw is a new fact. What is its meaning? Are the resemblances merely accidental, or do they have deeper foundation? . . . The Piltdown being was not a Dryopithecus, but may have had ancestral relations with some

species of this genus or family as close as those with the champanzees, if not even closer. A theory that the Eoanthropus may have evolved from such apes as represented by the Bohnerz molars, and that perhaps all man's evolution took place in western Europe, is a very seductive one and may possibly prove true, but it would be premature to give undue weight to this hypothesis.

The opinions which we have thus far been considering pertain chiefly if not entirely to the material described by Dawson and Smith Woodward in their first paper. We may now turn to those which specifically pertain to the later finds.

The next discoveries at Piltdown date from the summer of 1913. About them Mr. Dawson writes (Quart. Journ. Geol. Soc. London, vol. 70, p. 85, April 25, 1914):

> While our laborer was digging the disturbed gravel within 2 or 3 feet from the spot where the mandible was found, I saw two human nasal bones lying together with the remains of a turbinated bone beneath them in situ. The turbinal, however, was in such bad condition that it fell apart on being touched and had to be recovered in fragments by the sieve; but it has been pieced together satisfactorily by Mrs. Smith Woodward.
>
> All the gravel in situ excavated within a radius of 5 yards of the spot where the mandible was found was set apart and searched with especial care, and was finally washed and strewn as before mentioned. It was in this spread that Father Teilhard de Chardin, who worked with us three days last summer, on August 30, 1913, discovered the canine tooth of *Eoanthropus*, hereafter described.

Dawson died in 1916. On February 28, 1917, Sir Arthur Smith Woodward read before the Geological Society of London a paper entitled "Fourth Note on the Piltdown Gravel, with Evidence of a Second Skull of *Eoanthropus dawsoni*." In it he described the third set of Piltdown finds—namely, a left first lower molar tooth, a skull fragment from the supraorbital region of the right frontal bone adjacent to the middle line, and a small piece of the middle part of an occipital bone. The tooth and the piece of frontal were parts not represented among the previously known fragments; the piece of occipital duplicated a part of the original find, thus demonstrating the existence of a second skull. The circumstances of this discovery and the conclusions drawn from them are told as follows:

> One large field, about 2 miles from the Piltdown pit, had especially attracted Mr. Dawson's attention, and he and I examined it several times without success during the spring and autumn of 1914. When, however, in the course of farming, the stones had been raked off the ground and brought together into heaps, Mr. Dawson was able to search the material more satisfactorily and early in 1915 he was so fortunate as to find here two well-fossilized pieces of human skull and a molar tooth, which he immediately recognized as belonging to at least one more individual of *Eoanthropus dawsoni*. . . . From the new facts now described it seems reasonable to conclude that *Eoanthropus dawsoni* will eventually prove to be as definite and distinct a form of early man as was at first supposed, for the occurrence of the same type of frontal bone with the same type of lower molar in two separate localities adds to the probability that they belonged to one and the same species (pp. 3, 6).

By the two later sets of discoveries there were added to the original fragments a pair of nasal bones with an accompanying turbinate, two pieces of brain case, and two teeth. About them the history of the first find repeated itself. The parts of the skull were universally accepted as human, and no objection was raised to regarding them as having pertained to a second member of the same thick-skulled race as the original discoveries. But the teeth afforded subject matter for unending controversy. Woodward considered the canine to be a right lower tooth; other writers insisted that its proper place was in the left upper jaw. All agree that it is larger than any known human canine and that its tip must have extended beyond the level of the other teeth after the manner of an ape's canine. Regarding it as a part of the dawn man, Woodward said of this tooth: "In shape the canine resembles the milk canine of man and that of the apes more closely than it agrees with the permanent canine of any known ape. In accordance with a well-known palaeontological law, it therefore approaches the canine of the hypothetical Tertiary anthropoids more nearly than any corresponding tooth hitherto found." Those who regard the original *Eoanthropus* as a mixture of fragments pertaining to a man and an ape naturally consider the canine tooth as simian. Finding little difference between it and the canine of an adult female chimpanzee, they are for the most part content to associate it with the jaw and the molars. One author, however, declared that this association is not justified and that "the pulp cavities show that the canine and the molars belonged to individuals differing greatly in age. The skull and jaw were parts of one (human) individual, but the canine is the lower milk tooth of an unknown "humanoid anthropoid." (Lyne, Proc. Roy. Soc. Medicine, London, vol. 9, Odont., p. 50.)

But perhaps the most surprising differences of opinion are those to which the left lower molar has given rise. This tooth, it will be remembered, was, according to Sir Arthur Smith Woodward, "discovered by Mr. Dawson in the same locality as the two pieces of bone" pertaining to the third and last set of fragments. This association he regarded as very important because of its bearing on the Piltdown controversy. For, in his own words, "from the facts now described it seems reasonable to conclude that *Eoanthropus dawsoni* will eventually prove to be as definite and distinct a form of early man as was at first supposed; for the occurrence of the same type of frontal bone with the same type of lower molar in two separate localities adds to the probability that they belonged to one and the same species." On its face this argument appears to be a powerful one. Unquestionably, if a tooth identical in structure with those of the original mandible but pertaining to another individual were found associated with parts of a second Piltdown skull the case for uniting

all the previous finds as parts of one creature would be greatly strengthened. This view of the case is enthusiastically taken up by Professor Osborn, who writes (Natural History, vol. 21, pp. 580-581):

Scepticism as to the association of the chimpanzeelike jaw with the skull was very widespread. In the original description Smith Woodward himself proclaimed the resemblance of the jaw to that of a chimpanzee. The present writer was one of the American school of sceptics who finally reached the opinion that this was an instance of the accidental association of two wholly unrelated fossils. It would have been difficult to dislodge this opinion, so widely entertained in Europe and America, but for the overwhelming confirmation afforded to Smith Woodward by the discovery, announced in 1917,[4] of the remains of a second Piltdown man, not in the original quarry but at another exposure of the Piltdown gravels about 2 miles distant, a discovery made by the original finder, Dawson. If there is a Providence hanging over the affairs of prehistoric men, it certainly manifested itself in this case, because the three minute fragments of this second Piltdown man found by Dawson are exactly those which we should have selected to confirm the comparison with the original type—namely (1) a first lower molar tooth, (2) a bit of bone of the forehead near the right eyebrow, (3) the middle part of an occipital bone of the skull. Both the grinding tooth and the eyebrow region are absolutely distinctive. Placed side by side with the corresponding fossils of the first Piltdown man they agree precisely; there is not a shadow of difference. As shown in the accompanying photograph, published by permission of Dr. Smith Woodward, the two grinding teeth differ only in respect to age. The first Piltdown man was more advanced in years and the teeth were more worn; the second Piltdown man was younger and the teeth were unworn; but they present precisely the same characters. Smith Woodward very quietly published this confirmatory evidence without, however, alluding in any way to his critics or yielding to the natural temptation of writing "I told you so," a phrase which would certainly have appeared from a less patient and dignified pen.

Professor Osborn, who examined the actual specimen, tells us that the newly found tooth must have belonged to a second Piltdown man because its crown is unworn, its different degree of wear proving it to have pertained to a much younger individual than that which had possessed the original jaw with its smoothly ground-down molars. Sir Arthur Smith Woodward declared that the tooth agrees "very closely with that of the original specimen of *Eoanthropus dawsoni*," but that it is "more obliquely worn by mastication." He further says that "both the outer cusps are worn down to the dentine, the anterior exposing a slightly larger area than the posterior cusp. The small fifth cusp . . . is also worn down so as to expose a very small area of dentine," a description which would apply rather well to the teeth in the original jaw. Not degree but kind of wear is for him the determining feature of the tooth. In view of these contradictions of statement, unusual interest attaches to

[4] Woodward, A. S. Fourth Note on the Piltdown Gravel with Evidence of a Second Skull of *Eoanthropus dawsoni*. With an appendix by Prof. G. Elliot Smith. (Quart. Journ. Geol. Soc., London, Vol. 73, 1917, pp. 1-10, pl. I, figs. 1, 2.)

the opinion of a third authority who has studied the material at first hand. Doctor Hrdlička, whose experience in such matters is second to that of no living man, tells us (1922, p. 346) that—

> The additional molar tooth of the Piltdown remains is in every respect so much like the first molar of the Piltdown jaw that its procedure from the same jaws seems certain, and it would seem probable that the account of its having been discovered at a considerable distance away might be mistaken. The tooth agrees with those of the jaw perfectly not only in dimensions and every morphological character, but also in the degree and kind of wear. A duplication of all this in two distinct individuals would be almost impossible.

Doctor Hrdlička's suggestion that there may be some mistake in the published history of this tooth has met with no response. In thinking about it we must remember that Dawson personally described the circumstances of both of the earlier finds, but that the last set of discoveries was announced after his death and unaccompanied by any direct word from him.

Deliberate malice could hardly have been more successful than the hazards of deposition and recovery in so breaking the Piltdown fossils and losing the most essential parts of the original skull as to allow free scope to individual judgment in fitting the pieces together. This is particularly obvious when we look at the attempts to reconstruct the brain case. The four pieces of the original cranium lack some of the most important areas of contact with each other. Hence it has been possible for each student to widen or narrow the intervening areas according to his personal interpretation of the probabilities, and so to produce brain cases of narrower or broader form and of greater or less capacity. The resulting variations have been exhaustively discussed by Sir Arthur Keith in the second volume of his Antiquity of Man (new edition, 1925, pp. 514–602). According to the different reconstructions the form of the cranium may be completely human in striking contrast to the apelike jaw, or it may have partially simian features which cause this contrast to become less; its height may vary more than an inch, and the capacity of its brain cavity may range from 1,070 to 1,500 cubic centimeters.

SUMMARY OF OPINIONS ABOUT THE PILTDOWN MAN

(*Eoanthropus*)

There is only one point on which all authors agree—namely, that the fragments of the brain case and the nearly complete nasal bones pertain to a man. In striking contrast we find that there are not less than 20 points of disagreement.

(1)

The deposits in which the remains were found are of Pliocene age (Moir).

The deposits in which the remains were found are of Pleistocene age (Dawkins, Freudenberg and others).

(2)

The fact that the remains were found in stream-deposited material counts against the reference of all to the same individual (Miller, Ramström).

The fact that the remains were found in stream-deposited material does *not* count against the reference of all to the same individual (Jaekel, Keith, Pycraft, Woodward, and others).

(3)

The fragments all pertain to one creature, a man (Broom, Keith, Pycraft, Smith, Underwood, Woodward, and others).

The fragments pertain to two creatures—the skull to a man, the jaw and teeth to an ape (Miller, Ramström, Waterston, and others).

The fragments pertain to two creatures—the skull and jaw to a man, the canine tooth to an ape (Lyne).

The fragments pertain to two individuals, each a particular kind of man (Hrdlička, Puccioni).

(4)

The canine is a permanent tooth (Woodward and most writers).

The canine is a milk tooth (Lyne).

(5)

The degree of wear of the canine tooth is too great for the tooth to have been a milk tooth (Underwood).

The degree of wear of the canine tooth is *not* too great for the tooth to have been a milk tooth (Hopson).

(6)

The canine tooth came from the upper jaw and is most like the permanent upper canine of a female chimpanzee (Miller).

The canine tooth came from the lower jaw and is most like the lower milk canine of men and great apes (Woodward).

(7)

The left lower molar pertaining to the third set of fragments is worn in the same manner and to the same degree as the corresponding tooth in the original jaw (Hrdlička).

The left lower molar pertaining to the third set of fragments is worn in a different manner from the corresponding right tooth in the original jaw (Woodward).

The left lower molar pertaining to the third set of fragments is not worn at all (thus differing conspicuously from the worn corresponding tooth in the original jaw) (Osborn).

(8)

The specimens pertaining to the third set of fragments give additional support to the belief that the association of the jaw with the skull is justified (Gregory, Hellman, Osborn, Woodward).

The specimens pertaining to the third set of fragments give *no* additional support to the belief that the association of the jaw with the skull is justified (Hrdlička).

(9)

The jaw is straight like that of an ape (Woodward and most other writers).

The jaw is horseshoe-shaped like that of a man (Kleinschmidt).

(10)

The jaw more nearly resembles that of the Kaffir than that of the chimpanzee (Pycraft with approval of Broom, Keith and others).

The jaw more nearly resembles that of the chimpanzee than that of the Kaffir or any other race of man (Miller and many other writers).

(11)

The jaw was chinless (Woodward and most writers).

The jaw may not have been completely chinless (Dixon).

(12)

The jaw appears to be almost precisely that of an ape (Woodward).

The jaw is that of a chimpanzee (Boule, Miller, Ramström).

The jaw is utterly unlike that of any chimpanzee (O'Donoghue).

The jaw has many characters which make it human in spite of the fact that it presents many points of likeness to that of a chimpanzee

(Pycraft, with approval of Broom, Keith, Smith, Underwood, and Woodward).

The jaw is more like that of Neanderthal man than chimpanzee (Puccioni).

The jaw is oranglike (Frassetto).

The jaw is essentially a human jaw (Broom).

(13)

The molar teeth in the jaw are simian and within the variation limits for the corresponding teeth of great apes (Miller, Ramström, and others).

The molar teeth in the jaw differ conspicuously from those of all the great apes (Pycraft).

The molar teeth in the jaw are definitely those of a chimpanzee (Miller, Ramström, and others).

The molar teeth in the jaw are as unlike chimpanzee teeth as teeth can well be (Keith).

The molar teeth in the jaw find their nearest analogy in the teeth of the extinct apes of the genus *Dryopithecus* (Hrdlička).

The molar teeth in the jaw are human (Pycraft, Smith, and others).

(14)

The molar teeth in the jaw are ground down by a transverse movement which is physically impossible for any chimpanzee to accomplish (Broom).

The molar teeth in the jaw are ground down in the same manner as in a chimpanzee in the United States National Museum (Miller, Pycraft, 1918).

(15)

Taking the jaw and its teeth together the characters are nearest those of a young orang (Frassetto).

Taking the jaw and its teeth together the characters are nearest those of a chimpanzee (Miller, Ramström, and others).

(16)

The chimpanzee represented by the jaw was different from the living African species (Miller).

The chimpanzee represented by the jaw can not be distinguished from living African species (Ramström).

(17)

The presence of a hitherto unknown ape in England in the Pleistocene period involves an upheaval of paleontological teaching (Smith).

The presence of a hitherto unknown ape in England in the Pleistocene would not be in any way extraordinary (Boule).

(18)

Admitting that all the parts pertain to one creature, this is—

(*a*) A direct ancestor of modern man (Sutcliffe).

(*b*) A direct ancestor of Neanderthal man (Pilgrim).

(*c*) A representative of a line not leading to modern man or to Neanderthal man (Keith, Osborn, Smith).

(*d*) A missing link between man and the higher apes (Dawkins, Lankester).

(19)

The brain case of which the original fragments formed a part was essentially the same as that of modern man in both form and capacity, the latter about 1,400 cc. or more (Keith).

The brain case of which the original fragments formed a part was in general similar to that of modern man, but was lower, broader, and with less capacity, the latter about 1,100 cc. (Woodward).

The brain case of which the original fragments formed a part was unlike that of modern man in its remarkable breadth and small capacity (about 1,170 cc.); it differed, moreover, in details of structure which make it fall into harmony with the chimpanzee-like jaw (Smith and Hunter).

(20)

Eoanthropus is a valid genus distinct from *Homo*, and the name is appropriate because the creature lived at humanity's dawn (Woodward and most writers who accept the association of the fossils as parts of one individual).

Eoanthropus is not a valid genus distinct from *Homo*, and if it were the name would not be appropriate because a creature living so recently could not pertain to humanity's dawn (Boule, and others).

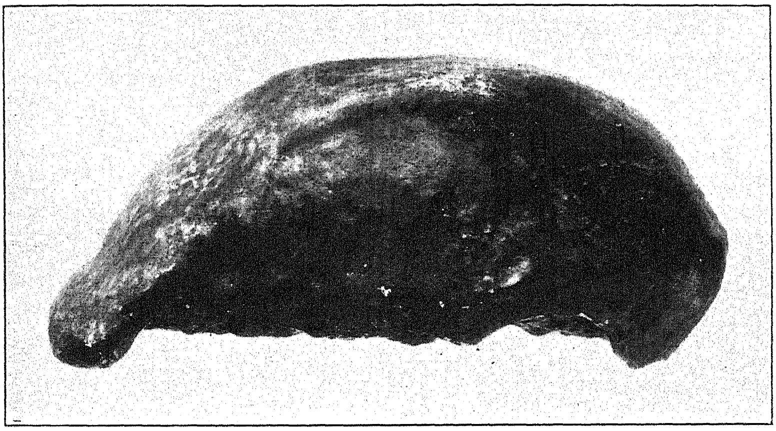
CONCLUSION

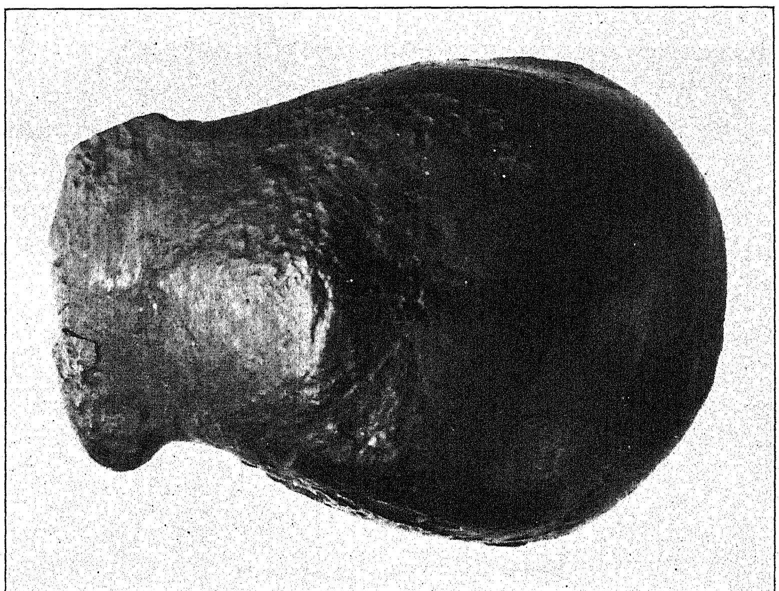
Having now reviewed the salient points in the controversy over human "missing links," we are probably in as good position as we are ever likely to be to form a definite opinion about the lessons taught by the discoveries of Dubois and Dawson—that is to say, so long as the specimens which these men found mark the limits of our knowledge. For the intense scrutiny to which the fragments have been subjected seems to have wrung from them the last secrets which they can have held. Two facts, if no others, must be admitted to stand out from the maze of opinion which we have been trying to follow—namely, that these fossils have furnished an unparalleled

stimulus to investigation, and that the things most needed now are more fossils and many of them.[5] While awaiting these further discoveries we should not hesitate to confess that in place of demonstrable links between man and other mammals we now possess nothing more than some fossils so fragmentary that they are susceptible of being interpreted either as such links or as something else. Superficial or prejudiced readers might regard this confession as having an important bearing on the subject of organic evolution in general and of man's origin in particular; but no conclusion could be more unjustified. The idea that all existing plants and animals are derived through some process of orderly change from kinds now extinct is supported by an array of facts too great and too well established to be weakened by doubts cast on alleged family records of any one creature. To understand how true this is we can, perhaps, do nothing more enlightening than to reread and meditate upon the second paragraph of the General Summary and Conclusion of Darwin's Descent of Man, a passage which, because of the footnotes that subsequent research has added to it, is even more full of meaning to-day then it was when first published 58 years ago:

The main conclusion arrived at in this work, and now held by many naturalists who are well competent to form a sound judgment, is that man is descended from some less highly organized form. The grounds upon which this conclusion rests will never be shaken, for the close similarity between man and the lower animals in embryonic development, as well as in innumerable points of structure and constitution, both of high and of the most trifling importance—the rudiments which he retains and the abnormal reversions to which he is occasionally liable—are facts which can not be disputed. They have long been known, but until recently they told us nothing with respect to the origin of man. Now, when viewed by the light of our knowledge of the whole organic world, their meaning is unmistakable. The great principle of evolution stands up clear and firm when these groups of facts are considered in connection with others, such as the mutual affinities of the members of the same group, their geographical distribution in past and present times, and their geological succession. It is incredible that all these facts should speak falsely. He who is not content to look, like a savage, at the phenomena of nature as disconnected, can not any longer believe that man is the work of a separate act of creation. He will be forced to admit that the close resemblance of the embryo of man to that, for instance, of a dog—the construction of his skull, limbs, and whole frame, independently of the uses to which the parts may be put, on the same plan with that of other mammals—the occasional reappearance of various structures, for instance, of several distinct muscles, which man does not normally possess, but which are common to the quadrumana—and a crowd of analogous facts—all point in the plainest manner to the conclusion that man is the codescendent with other mammals of a common progenitor.

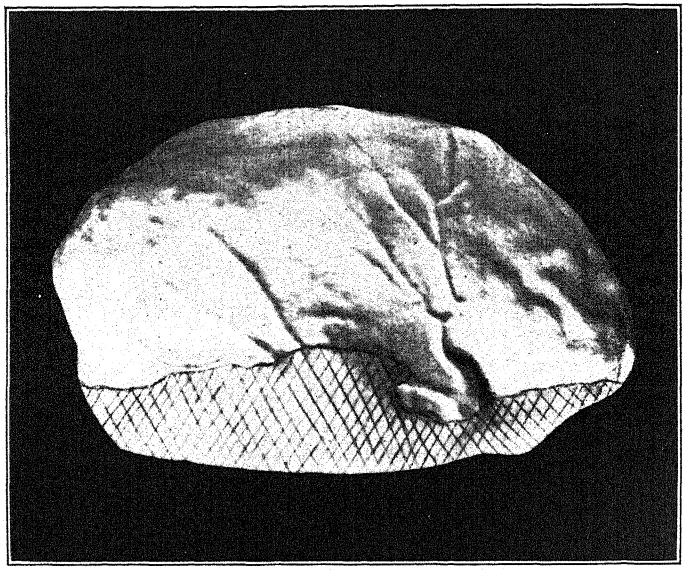
[5] La solution du problème de nos origines et surtout la détermination précise de notre lignée exigent de nouvelles découvertes de fossiles, de nombreux fossiles! (Boule.)

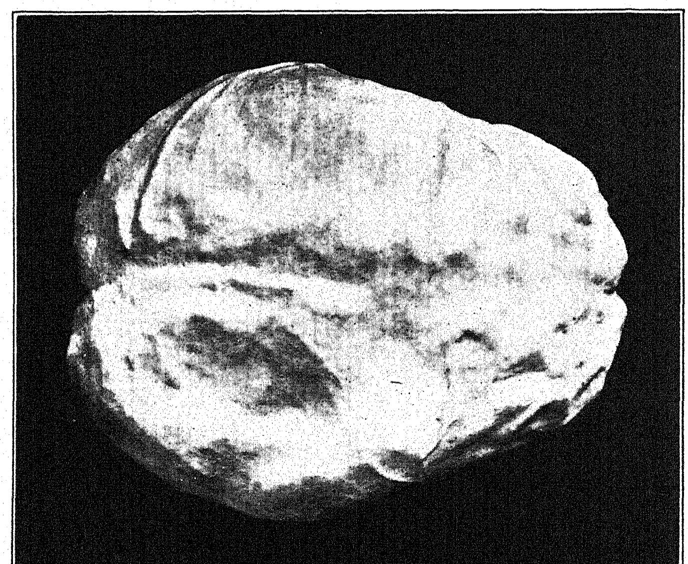




TWO VIEWS OF THE JAVA SKULLCAP

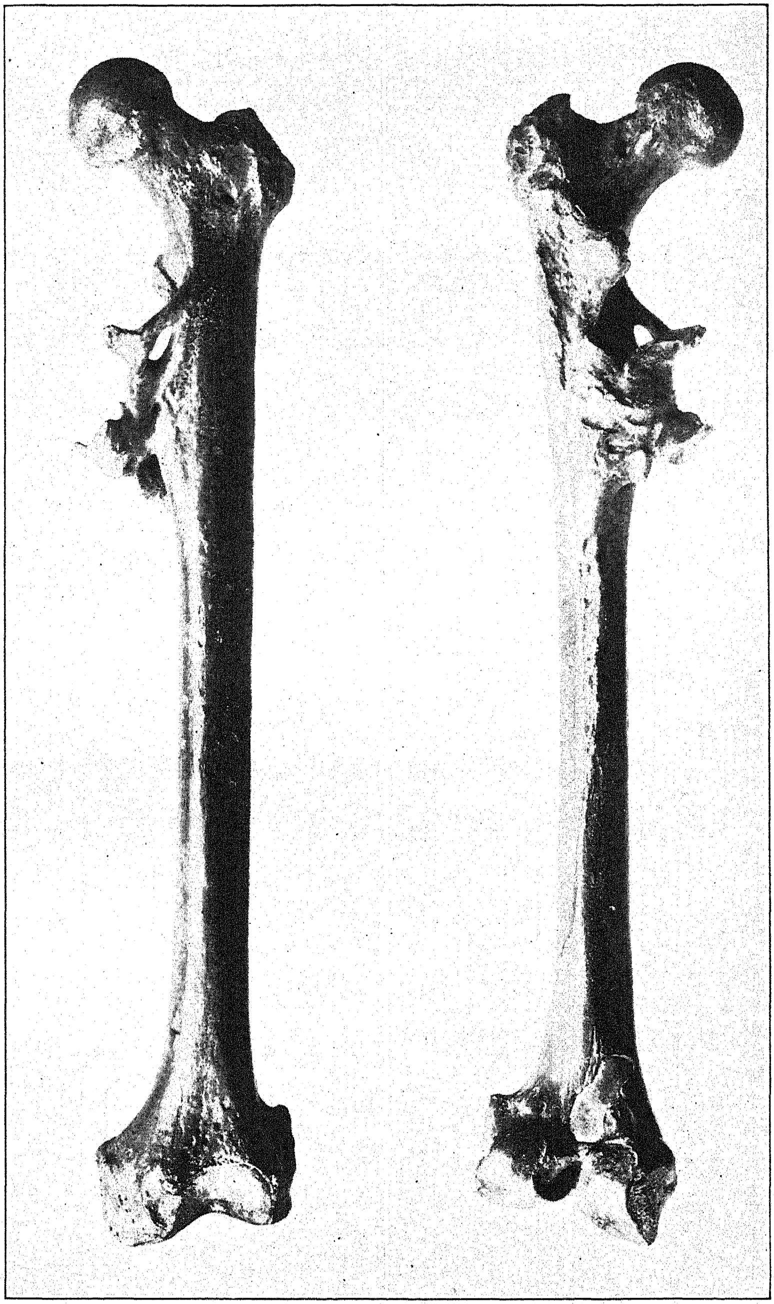
Photographs of cast in the U. S. National Museum. About × ½





TWO VIEWS OF A PLASTER CAST OF THE INTERIOR OF THE JAVA SKULLCAP

Photographs of a specimen in the U. S. National Museum. About × ½. (The cross-hatched area in the side view is not a part of the cast)



TWO VIEWS OF THE JAVA THIGH BONE

Photographs of a cast in the U. S. National Museum. About × ⅓

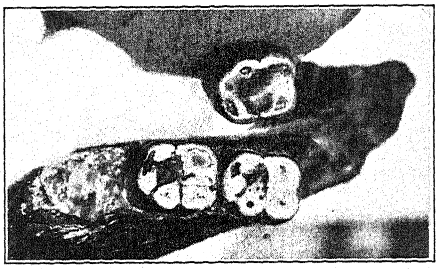


FIGURE 1.—PILTDOWN TEETH

The teeth in the jaw (below) compared with the subsequently described specimen (above)

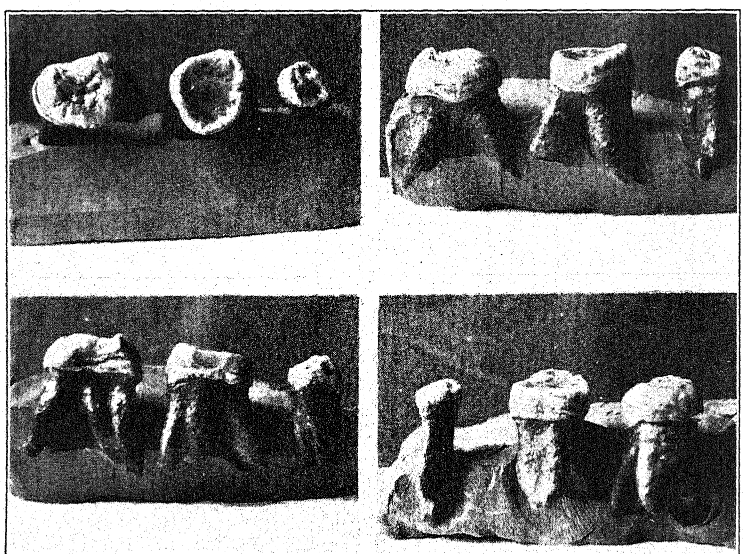
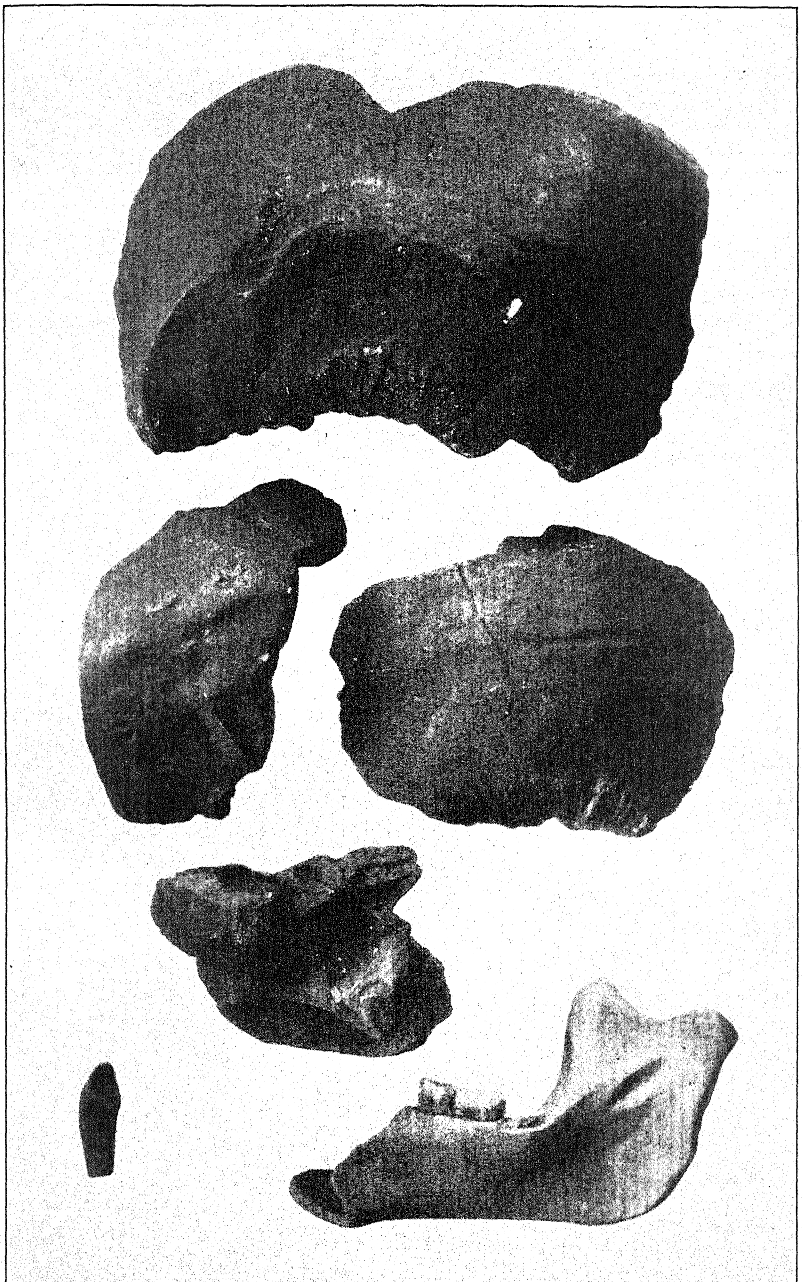


FIGURE 2.—JAVA TEETH

The photographs (natural size) on this plate were made from the original specimens by Prof. J. H. McGregor, to whose kindness we owe the opportunity to use them here. They have been previously published in Natural History, 1921 and 1925



THE PILTDOWN SKULL, JAW AND CANINE TOOTH

Photograph of casts in the U. S. National Museum. About × ½

BIBLIOGRAPHY

Not the least extraordinary feature of the controversy over human "missing links" is the abundance and diversity of the literature in which writers have put forward their contending views. While the general reader will probably find enough to satisfy his curiosity in the summary of opinions which I have presented, the more technical student may wish to consult the original sources. I have therefore prepared a rather extended bibliography of the Java man and the Piltdown man. Under neither heading have I attempted to assemble a complete list of titles, but I believe that the list includes the more essential articles which have appeared up to the end of the year 1928, including all those which are alluded to in the text of this article. For the Piltdown man I published two bibliographies in my papers of 1915 and 1918. In the present list I am entering all the titles which I have found since then. They are marked with asterisks.

THE JAVA MAN, PITHECANTHROPUS

ADLOFF, P. Einige Besonderheiten des menschlichen Gebisses und ihre stammesgeschichtliche Bedeutung. Zeitschr. f. Morph. und Anthrop., Vol. 10, pp. 106–121, 1907.

Pithecanthropus is an anthropoid in no way ancestral to man (p. 107).

AMOEDO, O. Les dents du *Pithecanthropus erectus* de Java. C. R. Ass. Française Adv. Sci. 1901, pp. 1193–1197, figs. 1–2. 1902.

The worn tooth is an anterior (not second) molar.

BERRY, EDWARD W. The age of *Pithecanthropus erectus*. Science, n. s., Vol. 37, pp. 418–420, March 14, 1913.

Notice of Schuster, 1911. Age of deposits undoubtedly Pleistocence, but the more exact dating undertaken by Schuster not justified.

BERRY, RICHARD J. A. and ROBERTSON, A. W. D. The Place in Nature of the Tasmanian Aboriginal as Deduced from a Study of his Calvarium. Part 1: His Relations to the Anthropoid Apes, *Pithecanthropus*, *Homo primigenius*, *Homo fossilis* and *Homo sapiens*. Proc. Roy. Soc. Edinburgh, vol. 31, pp. 41–69, Dec. 8, 1910.

Important comparisons. Accepts *Pithecanthropus* without question but deals with cap only.

BOULE, MARCELLIN. Fossil Men (translated by J. E. and J. Ritchie from the second French edition, 1923).

Pithecanthropus, pp. 93–110.

BRANCA, W. Vorläufiger Bericht über die Ergebnisse der Trinil-Expedition der Akademischen Jubiläums-Stiftung der Stadt Berlin. Sitzungsber. k. p. Akad. Wissensch., Berlin, 1908, pp. 261–273.

Preliminary notes on the Selenka expedition. The *Pithecanthropus* beds are of Pleistocene age.

BRANCO, W. Die menschenähnlichen Zähne aus dem Bohnerz der schwäbischen Alb. Jahreshefte d. Ver. f. Vaterland. Naturk. in Würtemberg, Stuttgart, vol. 54, pp. 1–144, 1898.

Pithecanthropus, pp. 98–112. No reason to suppose that the remains pertained to more than one individual, a fossil anthropoid ape with an unusually large brain. Each known genus of great apes has some feature in which it more nearly resembles man than does any of its relatives without thereby becoming a "link"; *Pithecanthropus* is best regarded as an ape in which the brain mass is the feature which thus parallels man.

CUNNINGHAM, D. J. Dr. Dubois' So-called Missing Link. Nature, vol. 51, pp. 428–429, Feb. 28, 1895.

"The so-called *Pithecanthropus* is in the direct human line, although it occupies a place on this considerably lower than any human form at present known." It can not be a link between man and the anthropoid apes.

CUNNINGHAM, D. J. Dr. Dubois' "Missing Link." Nature, vol. 53, pp. 115–116. December 5, 1895.

Skullcap is human though with resemblances to that of gibbon; teeth more human than simian; femur human.

DAMES, W. *Pithecanthropus*, ein Bindeglied zwischen Affe und Mensch. Deutsche Rundschau, vol. 88, pp. 368–384, September, 1896.

Regards the Java specimens as all pertaining to one animal, a true intermediate between man and apes. Tabulates the opinion of 23 authors (p. 375).

DENIKER, J. L'âge du Pithécanthrope. L'Anthropologie, vol. 19, pp. 260–269. 1908.

The animal is Quaternary and therefore not ancestral to man.

DIETERICH, W. O. Zur Alterbestimmung der Pithecanthropus-Schichten. Sitzungsber. Gesellsch. naturforsch. Freunde, Berlin, 1924, pp. 134–139. 1926.

DUBOIS, E. Pithecanthropus erectus. Eine menschenaehnliche Uebergangsform aus Java, pp. 1–39 [40], pls. 1–2, text figs. 1–3. Batavia, Java, 1894. (Original not seen; citation from the apparently photographic "Nachdruck" issued by G. E. Stechert & Co., New York, 1915.)

DUBOIS, E. *Pithecanthropus erectus*, betrachtet als eine wirkliche Uebergangsform und als Stammform des Menschen. Verh. Berl. Gesellsch. Anthrop. in Zeitschr. für Ethnologie, vol. 27, pp. 723–740, December, 1895.

DUBOIS, E. *Pithecanthropus erectus*, eine Stammform des Menschen. Anatomischer Anzeiger, vol. 12, pp. 1–22, figs. 1–10, Apr. 14, 1896.

DUBOIS, E. *Pithecanthropus erectus*, eine menschenähnliche Uebergangsform. C.-R. Troisième Congr. Internat. Zool., Leiden, pp. 251–271, pl. 2, 1896.

DUBOIS, E. On Pithecanthropus erectus: a transitional form between man and the apes. Sci. Trans. Royal Dublin Soc., ser. 2, vol. 6, 66. 1–18. February, 1896. Modified from the paper read at Leiden, September 21, 1895.

DUBOIS, E. Quatorzième conférence annuelle transformiste. Le "*Pithecanthropus erectus*" et l'origine de l'homme. Bull. Soc. Anthrop., Paris, ser. 4, vol. 7, pp. 460–467, 1896.

DUBOIS, E. Näheres über den *Pithecanthropus* als menschenähnliche Uebergangsform. Monatsschr. für Anat. und Physiol. vol. 13, pp. 1–26, 1896.

DUBOIS, E. Remarks Upon the Brain-Cast of *Pithecanthropus erectus*. Proc. fourth Internat. Congr. Zool., Cambridge, 1898, pp. 78–95, 1899.

I found the cephalization of Pithecanthropus erectus to be nearly the half of that occurring in man and nearly the double of that occurring in the anthropoid apes.

DUBOIS, E. *Pithecanthropus erectus*—A form from the Ancestral Stock of Mankind. Ann. Rep. Smithsonian Inst., 1898, pp. 445–459, pls. 1–2, figs. 1–4, 1899.

A translation of Dubois's paper of Apr. 14, 1896. Some of the original illustrations are omitted, and some new ones are added.

DUBOIS, E. Enige van nederlandschen kant verkregen uitkomsten met betrekking tot de kennis der Kendeng-Fauna (Fauna van Trinil). Tijdschr. Kon. Nederl. Aardrijkskund. Genootsch. Amsterdam, ser. 2, vol. 24, pp. 449–458, May 15, 1907.

DUBOIS, E. Das geologische Alter der Kendeng- oder Trinil-Fauna. Tijds. K Ned. Aardrijksk. Genootsch., Amsterdam, ser. 3, vol. 25, pp. 1235–1270, pl. 39, 1908.

The fauna is not Quaternary but late Pliocene.

DUBOIS, E. Over de Plaats von *Pithecanthropus* in het zoölogisch systeem. Arch. Mus. Teyler, Haarlem, ser. 3, vol. 1, pp. 142–149, 1912.

DUBOIS, E. On the Principal Characters of the Cranium and the Brain, the Mandible, and the Teeth of *Pithecanthropus erectus*. Versl. Wiss. Nat. Afd. K. Akad. Wet. Amsterdam, vol. 27, pp. 265–278, 1924.

DUBOIS, E. On the Brain Quantity of Specialized Genera of Mammals. Versl. Wiss. Nat. Afd. K. Akad. Wet. Amsterdam, vol. 27, pp. 430–437, 1924.

DUBOIS, E. Figures of the Calvarium and Endocranial Cast of a Fragment of the Mandible and Three Teeth of *Pithecanthropus erectus*. Versl. Wiss. Nat. Afd. K. Akad. Wet. Amsterdam, vol. 27, pp. 459–464, 11 plates, 1924.

DUBOIS, E. Over de voornaamste onderscheidende eigenschappen van den schedel en de hersenen, de onderkaak en het gebit van Pithecanthropus erectus. Versl. Wiss. Nat. Afd. K. Akad. Wet. Amsterdam, vol. 33, pp. 135–148. 1924.

DUBOIS, E. On the Principal Characters of the Femur of *Pithecanthropus erectus*. Proc. K. Akad. Wet. Amsterdam, vol. 29, pp. 730–743, 33 figs., 1926.

ELBERT, J. Ueber das Alter der Kendeng-Schichten mit Pithecanthropus erectus Dubois. Neues Jahrb. Min. Geol. und Paläont., Stuttgart, Beilagebd., 25, pp. 648–662, 1908.

The deposits are lower Pleistocene (Unterdiluvial)

GIESELER, W. Ueber die hauptsächlichsten morphologischen Charaktere der *Pithecanthropus* Calotte. Anthrop. Anz., Stuttgart, vol. 3, pp. 117–119, 3 plates, 1926.

GIESELER, W. Neuere Forschungen zum *Pithecanthropus*-problem. Forschungen und Fortschritte, Berlin, vol. 4, pp. 150–151, 1 fig., May 20, 1928.

GIUFFRIDA-RUGGERI, V. La posizione del bregma nel cranio del "Pithecanthropus erectus" e la tendenza neo-monogenista in Germania. Atti Soc. Romana Anthrop., vol. 10, pp. 20–38. 1904.

GIUFFRIDA-RUGGERI, V. Il Pithecanthropus erectus e l'origine della specie umana. Revista di Scienza, Bologna, year 1, vol. 2, pp. 297–303. 1907.

GREGORY, WILLIAM K., and HELLMAN, MILO. Further Notes on the Molars of *Hesperopithecus* and of *Pithecanthropus*. Bull. Amer. Mus. Nat. Hist., vol. 48, pp. 509–526, Dec. 4, 1923.

GREGORY, WILLIAM K., and HELLMAN, MILO. The crown patterns of fossil and recent human molar teeth and their meaning. Natural History, vol. 26, pp. 300–309, figs. 1–9. 1926.

HAECKEL, Ernst. Systematische Phylogenie der Wirbelthiere, part 3, pp. 633, 634, 1895.

Dubois' *Pithecanthropus* is placed among the great apes (Menschenaffen), of which it is said to be the one most resembling man (p. 633) and perhaps belonging to our direct ancestors (p. 634). The femur may be human (p. 633). Haeckel's *Pithecanthropus alalus* (pp. 601, 641) is a hypothetical ancestral form.

HAECKEL, ERNST. On Our Present Knowledge of the Origin of Man. Ann. Rep. Smithsonian Inst., 1898, pp. 461–480. 1899. A discourse delivered at the Fourth International Congress of Zoologists at Cambridge, England, Aug. 26, 1898. Translated from the author's edition in German printed at Bonn, 1898.

"The *Pithecanthropus erectus* of Dubois is in fact a relic of that extinct group to which as long ago as in 1886 I gave the name *Pithecanthropus*. He is the long-sought 'missing link' in the chain of the highest primates" (p. 469).

HEPBURN, D. The Trinil Femur (*Pithecanthropus erectus*) Contrasted with the Femora of Various Savage and Civilized Races. Journ. Anat. Physiol. norm. path., ser. 3, vol. 11, pp. 1–17, figs.

All characters of the femur are within the limits of human variation.

HILBER, V. Alter der *Pithecanthropus*-Schichten. Centralbl. für Mineral. Geol. u. Paläont., Stuttgart, 1921, pp. 149–154, Mar. 1, 1921.

The age of the deposits is upper Pliocene as originally determined by Dubois.

HOUZÉ, E. Le *Pithecanthropus erectus*. Bull. Soc. Anthrop. Bruxelles, vol. 15, pp. 18–55. 1896.

Skull, teeth, and femur are all human. It therefore makes no difference whether they pertained to one individual or not (p. 22).

HRDLIČKA, ALEŠ. The Most Ancient Skeletal Remains of Man. Ann. Rep. Smithsonian Inst., Append., 1913, pp. 491–552, 1914.

Pithecanthropus, pp. 495–501, pls. 2–5, text figs. 1–2. The impression which a comprehensive study of the whole skullcap carries to the observer is that it represents a hitherto-unknown primate form, which, whatever it may eventually be identified with and whether or not man's direct ancestor, stands morphologically between man and the known anthropoid apes, fills an important space in the hitherto existing large void between the two, and constitutes a precious document for the natural history of man. . . . The femur plainly belonged to a strong being maintaining erect or near-erect posture and marching mostly or entirely biped, as man (p. 501).

JAEKEL, OTTO. [Remarks on *Pithecanthropus*.] Verh. Berl. Gesellsch. Anthrop., in Zeitschr. für Ethnologie, vol. 27, pp. 747–748, December, 1895.

No difficulty in associating the remains as parts of one individual. Taken together they constitute the best transition form known to date.

KATE, H. TEN. [Notice of Dubois' paper in Verslag van het mijnwezen over het 3° kwartaal 1892. Extra bijvoegsel der Javansche Courant No. 10, Batavia, 1893, p. 10 sq.] Nederl. Koloniall Centraalblad, Amsterdam, vol. 1, pp. 82–83, November, 1894.

The remains are those of an anthropoid.

KEITH, A. *Pithecanthropus erectus*—A Brief Review of Human Fossil Remains. *Science Progress*, vol. 3, pp. 348–369, July, 1895.

Regards the fossils as indicating "a human race more primitive than any hitherto discovered."

KEITH, A. The Problem of *Pithecanthropus*. Nature, vol. 87, pp. 49–50, July 13, 1911.

KEITH, A. The Antiquity of Man. New Edition, 1925.

Pithecanthropus, pp. 419–437.

KEITH, A. Darwin's theory of Man's Descent as it Stands To-day. Science, n. s., vol. 66, pp. 201–208, Sept. 2, 1927; Nature, vol. 120, suppl., pp. 14–21, Sept. 3, 1927. (The presidential address before the British Association for the Advancement of Science given at Leeds on Aug. 31, 1927.)

KLAATSCH, H. Der gegenwärtige Stand der Pithecanthropus-Frage. Zool. Centralbl., vol. 6, pp. 217–235, April, 1899.

Summarizes literature to date (44 titles). Accepts reference of fossils to one individual, a creature related to the gibbons but distinctly approaching the human type in the great capacity of the cranium. Femur is not strictly human, but the animal which possessed it walked erect.

KOLBE, H. Ueber den angeblichen Affenmenschen, Pithecanthropus erectus Dubois. Naturwiss. Wochenschr., vol. 10, pp. 70–72. Feb. 3, 1895.

No sufficient proof that the remains came from one animal. The femur is human, the tooth simian, the skull cap is intermediate in character.

KOLLMAN, J. [Remarks on *Pithecanthropus*.] Verh. Berl. Gesellsch. Anthrop., in Zeitschr. für Ethnologie, vol. 27, pp. 740–744, December, 1895.

The animal is a gigantic gibbon. Human ancestral forms are not likely to have been gigantic.

KOLLMAN, J. Neue Gedanken über das alte Problem von der Abstammung des Menschen. Globus, vol. 87, pp. 140–148, Feb. 23, 1905.

Pithecanthropus undoubtedly belongs to the anthropoid apes—the representative of a line which reached the end of its adaptability and then became extinct, leaving no descendants.

KRAUSE, W. *Pithecanthropus erectus*, eine menschenähnliche Uebergangsform aus Java. Verh. Berl. Gesellsch. Anthrop., in Zeitschr. für Ethnologie, vol. 27, pp. 78–81, 1895.

Skull and teeth those of an ape, femur human.

KRAUSE, W. [Remarks on *Pithecanthropus*.] Verh. Berl. Gesellsch. Anthrop., in Zeitschr. für Ethnologie, vol. 27, p. 440, 1895.

It is doubtful whether the wisdom tooth is of the same age as the other remains.

KRAUSE, W. Rekonstruktion des Schädels vom *Pithecanthropus erectus* Dubois, Verh. Berl. Gesellsch. Anthrop., in Zeitschr. für Ethnologie, vol. 28, p. 362, 1896.

Exhibition of a drawing in which the skull is reconstructed like that of a gigantic gibbon. The lower jaw would be 1½ times as long as the human jaw and the radius would have had a length of about 1 meter. Such an excess of size over that of related living species is an ordinary occurrence among extinct mammals.

LECHE, WILHELM. Der Mensch, sein Ursprung und seine Entwicklung, Jena, 1911.

Pithecanthropus, pp. 353. Whether or not the creature stands in man's ancestral line is an unanswerable question.

LUSCHAN, F. VON. [Remarks on *Pithecanthropus.*] Verh. Berl. Gesellsch. Anthrop., Zeitschr. für Ethnologie, vol. 27, p. 81, 1895.

The skullcap does not resemble that of the gibbon more than it does that of other forms. The femur resembles in general that of man, but, if correctly figured, would indicate a greater pelvic breadth than in modern man. No reason to doubt that femur and skullcap came from one individual.

LYDEKKER, RICHARD. Review of "*Pithecanthropus Erectus*, eine Menschenaehnliche Uebergansform aus Java" by E. Dubois. Nature, vol. 51, p. 291, January 24, 1895.

"With regard to the skull . . . there appears every reason to regard it as that of a microcephalous idiot of an unusually elongated type".

MAIR, R. Ueber die Bregmagegend und die Lage des Bregma mit besonderer Berücksichtigung des *Pithecanthropus.* Zeitschr. Morph. Anthrop., Stuttgart, vol. 22, pp. 435–480, 1 pl., 20 text figs., 1922.

MANOUVRIER, L. Discussion du "*Pithecanthropus erectus*" comme précurseur présumé de l'homme. Bull. Soc. Anthrop. Paris, ser. 4, vol. 6, pp. 12–47, 1895.

The skullcap, tooth and femur can not be regarded with certainty as having pertained to one individual or one species, but there is no theoretical impossibility in such a view. Impossible to demonstrate either a human or simian origin of the fossils. The question must remain open pending further discoveries.

MANOUVRIER, L. Deuxième étude sur le "*Pithecanthropus erectus*" comme précurseur présumé de l'homme. Bull. Soc. Anthrop. Paris, ser. 4, vol. 6, pp. 553–651, 1895.

Concludes, after direct examination of the specimens, that all pertained to one individual, a representative of an anthropomorph race approaching the lowest living human races and the race of Spy on the one hand and the anthropoid apes on the other, in such a manner that, until there is proof to the contrary, we may regard the "missing link" as found.

MANOUVRIER, L. Le Pithecanthropus erectus et la théorie transformiste. Revue Scientifique, ser. 4, vol. 5, pp. 289–299. Mar. 7, 1896.

MANOUVRIER, L. Réponse aux objections contre le *Pithecanthropus.* Bull. Soc. Anthrop. Paris, ser. 4, vol. 7, pp. 396–460, 1896.

MANOUVRIER, L. Quatorzième conférence annuelle transformiste. Le "*Pithecanthropus erectus*" et l'origine de l'Homme. Bull. Soc. Anthrop. Paris, ser. 4, vol. 7, pp. 467–4.3, 1896.

MANOUVRIER, L. On Pithecanthropus erectus. Amer. Journ. Sci., ser. 4, vol. 4, pp. 213–234. September, 1897. Translation, by MacCurdy, of parts of three articles.

MARSH, O. C. On the Pithecanthropus erectus, Dubois, from Java. Amer. Journ. Sci., ser. 3, vol. 49, pp. 144–147, 3 figs. (from Dubois), February, 1895.

MARSH, O. C. On the Pithecanthropus erectus, from the Tertiary of Java. Am. Journ. Sci.,ser. 4, vol. 1, pp. 475–482, June, 1896.

Describes discovery. He saw the specimens at Leiden in 1895. Convinced that the deposits were Tertiary and that all parts came from one individual. Agrees with the conclusions of Dubois.

MARTIN, R. Kritische Bedenken gegen den *Pithecanthropus erectus* Dubois. Globus, vol. 67, pp. 213–217, March, 1895.

The remains are human; skull of the Neanderthal type; wisdom tooth wholly human; femur human.

MARTIN, R. Weitere Bemerkungen zur *Pithecanthropus*-Frage. Zürich, pp. 1–18, 1 pl., March, 1906.

Reviews literature to date and reaffirms his earlier views with slight modifications.

[MATSCHIE, P.] Anthropopithecus (sic) erectus Eug. Dubois. Naturwiss. Wochenschr., vol. 9, pp. 59–60, Feb. 4, 1894.

MATSCHIE, P. Noch einmal *Anthropopithecus* (sic) *erectus* Eug. Dubois. Naturwiss. Wochenscrift, vol. 10, pp. 81–82, Feb. 17, 1895.

The fossils are not certainly all parts of one individual. Femur not ape; teeth not very different from human; skullcap essentially human, perhaps pathological.

MATTHEW, W. D. The Ape-Man of Java. Natural History, vol. 28, pp. 577–588, 7 figs., December, 1928.

It is simpler to assume that the fragments all belonged to one species. "The probabilities are that the Pithecanthropus was in some respects nearer to man, in others to one or another of the great apes, and had likewise some peculiarities of its own" (p. 586).

MCGREGOR, J. H. Recent Studies on the Skull and Brain of *Pithecanthropus*. Natural History, New York, Vol. 25, pp. 544–559, figs. 1–9, 1925.

Discusses restorations of the skull and endocranial cast. Reproduces original photographs of the teeth, 4 views of each (fig. 10).

MIJSBERG, W. A. Over het in 1926 te Trinil gevonden en ten onrechte als rest van het schedelkak van een praehistorischen mensch beschouwde fossil. Geneesekundig Tijdschrift voor Nederlandsch-Indie, Afl. 1, Deel. 67, pp. 1–7, 1927.

MILLER, Gerrit S., Jr. Notes on the Casts of the *Pithecanthropus* Molars. Bull. Amer. Mus. Nat. Hist., Vol. 48, pp. 527–530, figs. 14–15, Dec. 4, 1923.

Photographs of casts compared with the corresponding teeth of 16 Bornean orangs. So far as can be judged from this comparison, the Java teeth have no characters which would separate them generically from the orang or indicate any relationship with man.

NEHRING, A. Menschenreste aus einem Sambaqui von Santos in Brasilien, unter Vergleichung der Fossilreste des Pithecanthropus erectus Dubois. Verh. Berl. Gesellsch. Anthrop., in Zeitschr. für Ethnologie, vol. 27, pp. 710–721, figs. 1–4, 1895.

All the parts belong to the same species which represents a "Mittelform" between the lowest human races and the highest anthropomorphs. The form of the skullcap is approached by that of a human skull from a prehistoric deposit near Santos, Brazil.

NEHRING, A. Ein Pithecanthropus ähnlicher Menschenschädel aus den Sambaquis von Santos, in Brasilien. Naturwiss. Wochenschr., vol. 10, pp. 549–552, November 17, 1895. Text slightly different from that of previous paper.

NEHRING, A. Die Capacität des Schädels von Pithecanthropus erectus. Naturwiss. Wochenschr., vol. 11, pp. 344–345, July 12, 1896.

No reason to place the genus in a family distinct from the Hominidæ.

NEVIANI, A. Il Pitecantropo o la scimmia-uomo e la teoria dell' evoluzione. Rivista di sociologia, Roma, vol. 3, pp. 205–233, 1896.

NEVIANI, A. Il Pitecantropo e la origine naturale dell' Uomo. Riv. Ital. Sci. Nat., vol. 16, pp. 113–117, 135–139, 1896; vol. 17, pp. 12–18, 38–44, 1897.

OBERMAIER, HUGO. Der Mensch der Vorzeit, 1912.

Pithecanthropus, pp. 370–375. Concludes that the skullcap came from one kind of ape (*Pithecanthropus* proper), the teeth from another, not yet described, while the femur may have been human.

OSBORN, HENRY F. Men of the Old Stone Age. New York, ed. 2, 1916.

Pithecanthropus, pp. 72–84, figs. 29–41.

OSBORN, H. F. Dawn-Man Appears as Our First Ancestor. The New York Times, Sunday, Jan. 9, 1927, Sec. XX, p. 3, figs. 5.

The Trinil man is a dawn man and not an ape man. He walked erect, he thought as a man, he probably spoke as a man, although his vocabulary was limited. . . . A welcome gift from anthropology to humanity is this banishment of the myth and bogie of our ape-ancestry.

PEARSALL, W. BOOTH. The teeth of Pithecanthropus erectus. British Dental Journal, vol. 28, pp. 869–874, figs. 1–3, August 15, 1907.

The teeth are accepted as human; the worn molar is m^3 left, the unworn molar is m^3 right. Both could have come from one individual.

PERVINQUIÈRE, L. Le Pithécanthrope et l'homme fossile de la Chapelle-aux-Saints. Rev. Sci., Paris, ser. 5, vol. 11, pp. 39–41, Jan. 9, 1909.

Pithecanthropus was a contemporary of quaternary man and therefore not a human ancestor. The fossil is interesting but so fragmentary as to provide an open door to discussions.

PETTIT, A. Le *Pithecanthropus erectus.* L'Anthropologie, vol. 6, pp. 65–69, February, 1895.

Gives several reasons for rejecting Dubois' view and regarding the remains as human.

RAMSTRÖM, MARTIN. Der Java-Trinil-Fund "*Pithecanthropos*" oder können die "*Eoanthropos*"- and *Pithecanthropos*-Funde uns zuverlässige Aufschlüsse über die Anthropogenesis geben? Upsala Läkareförenings Förhandl., N. F., vol. 26, Festskr. Prof. J. Aug. Hammar, art. 29, pp. 1–37, 1921.

ROSENBERG, E. [Remarks on *Pithecanthropus.*] C.-R. Troisième Congr. Internat. Zool., Leiden, 1895, p. 272, 1896.

Expresses doubt as to whether the femur differs from that of man. The skullcap indicates that its possessor did not walk erect.

SCHLOSSER, M. Die neueste Litteratur über die ausgestorbenen Anthropomorphen. Zool. Anzeiger, vol. 23, pp. 289–301, May 28, 1900.

Pithecanthropus, pp. 299–301. The known material is insufficient to supply a basis for positive conclusions. So far as it goes it merely proves that *Pithecanthropus* is more widely separated from the great apes than from man. Can not be a gigantic gibbon.

SCHUSTER, J. Ein Beitrag zur *Pithecanthropus*-Frage. Sitzungsber. k. bayer. Akad. Wissensch., München, Math.-phys. Klasse, Jahrg. 1909, Abhandl. 17, 1910.

SCHUSTER, J. Monographie der fossilen Flora der *Pithecanthropus*-Schichten. Abhandl. k. bayer. Akad. Wissench., München, Math-phys. Klasse, Vol. 25, Abhandl. 6, 1911.

SCHWALBE, G. Studien über *Pithecanthropus erectus* Dubois. 1. Theil. 1. Abtheilung. Zeitschr. für Morph. u. Anthrop., vol. 1, pp. 16–228, 1899.

The skullcap can not be that of a large gibbon, nor can it be referred to a member of any of the other living genera of anthropoids; on the contrary it rather nearly resembles the corresponding part of Neanderthal man in the majority of its characters.

SCHWALBE, G. Studien zur Vorgesch. des Menschen. Zeitschr. für Morph. und Anthrop., vol. 9, Sonderheft, pp. 5–228, pls. 1–4, text figs. 1–13, May 26, 1906.

Regards *Pithecanthropus* as a member of the Hominidae and a direct ancestor of Neanderthal man, which in turn is a direct ancestor of modern man. The line thus formed diverged from the line of the great apes in the Miocene, and the common stock for both may be represented by *Dryopithecus* (p. 24).

SCHWALBE, G. Studien über das Femur von *Pithecanthropus erectus* Dubois, Zeitschr. Morph. und Anthrop., vol. 21, pp. 289–360, 1921.

Femur has slight peculiarities but is human. It is more probable that all specimens came from one individual than that the femur is human and the skull simian.

SELENKA, M., und DUBOIS, E. Die fossilen Zähne von Trinil. Tijdschr. K. Ned. Aardr. Gen. ser. 2, vol. 26, pp. 398–401, 1909.

SELENKA, L., und BLANCKENHORN, M. Die *Pithecanthropus*-Schichten auf Java. Geologische und palaeontologische Ergebnisse der Trinil-Expedition, Leipzig, 1911, 310 pp., 32 pls.

SOLLAS, D. J. "*Pithecanthropus erectus*" and the Evolution of the human Race. Nature, vol. 53, pp. 150–151, Dec. 19, 1895.

If the Neanderthal skull be lifted a little upward in the scale of time, a curve can be made to pass through it, the European and Javan skulls, and this when prolonged downward will approximate to the stem either of *Pliopithecus* . . . or . . . *Dryopithecus*.

SYMINGTON, J. Endocranial Casts and Brain Form: A Criticism of Some Recent Speculations. Journ. Anat. and Physiol, vol. 50, pp. 111–130, January, 1916.

The author concludes "that the simplicity or complexity of the cerebral fissures and convolutions can not be determined with any degree of accuracy from endocranial casts, even on complete skulls much less on reconstructions from imperfect skulls." Therefore the "deductions with reference to the primitive and simian features of the brains of certain prehistoric men [made] from an examination of their endocranial casts are highly speculative and fallacious."

TILNEY, FREDERICK. The Brain from Ape to Man. New York, Paul B. Hoever, vols. 2, pp. XXVII+1120, figs. 539, 1928.

Of *Pithecanthropus* the author writes, p. 875 (italics in the original): *He had learned to speak*—to communicate in verbal language.

TOPINARD, P. [Review of] Prof. Sir William Turner. Sur la description de M. Dubois des restes récemment trouvés à Java et attribués par lui à un *Pithecanthropus erectus*. L'Anthropologie, vol. 6, pp. 605–607, October, 1895.

The skullcap is that of a Neanderthal man; the femur is perhaps feminine, the molar tooth is probably from an extinct species of orang (p. 607).

TURNER, SIR W. On M. Dubois' Description of Remains Recently Found in Java and named by him *Pithecanthropus erectus*. With Remarks on the So-called Transitional Forms Between Apes and Man. Journ. Anat. Physiol. norm. path., ser. 2, vol. 9, pp. 424–445.

Femur unqualifiedly human. Probably did not belong with the skullcap.

VALLOIS, H. V. Sur quelques caractères du fémur du *Pithécanthrope*. C.-R. Acad. Sci. Paris, vol. 168, pp. 739–741, 1919.

In the relative dimensions of its lower epiphysis and the obliquity of its diaphysis the femur has all the characters of recent man; it differs from the femurs of the anthropoids and especially from that of the gibbon.

VERNEAU, R. Encore le *Pithecanthropus erectus*. L'Anthropologie, vol. 6, pp. 725–726, December, 1895.

We have the right to conclude that the animal was an intermediate between man and the living great apes. The teeth are not human; the skullcap is not truly human; the femur appears to be really human but did not come from same individual as the other parts.

VIRCHOW, RUD. [Remarks on *Pithecanthropus.*] Verh. Berl. Gesellsch. Anthrop., in Zeitschr. für Ethnologie, vol. 27, pp. 81–87, 1895.

The circumstances of the find do not support the belief that the fossils pertained to one individual. The skullcap is much like that of a gibbon; the only character of the femur which distinguishes it from the femur of a gibbon is its excessive size.

VIRCHOW, RUD. *Pithecanthropus erectus* Dubois. Verh. Berl. Gesellsch. Anthrop., in Zeitschr. für Ethnologie, vol. 27, pp. 336–337, 1895.

Regards the Trinil deposits as lower Pliocene.

VIRCHOW, RUD. *Pithecanthropus erectus.* Verh. Berl. Gesellsch, Anthrop., in Zeitschr. für Ethnologie, vol. 27, pp. 435–440, pls. 6–7, 1895.

Skull that of a great ape. The abnormal bony outgrowths on the femur indicate a condition so serious as to give support to the idea that this bone may have pertained to a man who was nursed by his family and fellows; but the idea of a successful cure in an ape is not excluded, and the question must be decided by the structural characters of the bone.

VIRCHOW, RUD. Weitere Mittheilungen über den *Pithecanthropus erectus* Dub. Verh. Berl. Gesellsch. Anthrop., in Zeitschr. für Ethnologie, vol. 37, pp. 648–656, 1895.

The ape character of the skull is obvious. The teeth may have come from one individual, but they are ape's teeth and not a man's. The skullcap is too small to have accompanied the femur as part of a man.

VIRCHOW, RUD. [Remarks on *Pithecanthropus.*] Verh. Berl. Gesellsch. Anthrop., in Zeitschr. für Ethnologie, vol. 37, pp. 744–747, figs. 1–3, 1895.

Skullcap closely agrees with that of a gibbon when reduced to same size (fig. 1). According to the structure of the femur, there is no difficulty in regarding it as that of a gigantic gibbon.

VIRCHOW, RUD. Exostosen und Hyperostosen von Extremitätenknochen des Menschen, in Hinblick auf den *Pithecanthropus.* Verh. Berl. Gesellsch. Anthrop., in Zeitschr. für Ethnologie, vol. 37, pp. 787–793, pl. 9, 1895.

Closer comparison of the abnormal growths on the fossil with those on human femurs has shown some noticeable differences.

VIRCHOW, RUD. [Remarks on Pithecanthropus.] C.-R. Troisième Congr. Internat. Zool., Leiden, 1895, p. 272, 1896.

Inclines to the idea that the femur is human, because of its diseased condition, but admits that the characters of the bone make it resemble the femur of the gibbon.

VOLZ, W. Ueber *Pithecanthropus erectus* Dub. Eine menschenähnliche Uebergangsform aus Java. Jahres-Ber. schles. Ges. vaterl. Cultur, Sitz. d. zool. bot. Sect., vol. 74, pp. 5–8, January, 1896.

Pithecanthropus is a gibbonlike ape, about the size of a man, evidently more highly organized than living anthropoids, but still an ape. The gap between man and ape is in no wise closed by this find.

VOLZ, W. Demonstration eines Schädel-Abgusses von *Pithecanthropus erectus.* Jahres-Ber. schles. Ges. vaterl. Cultur, Sitz. d. Naturwiss. Sect., vol. 75, pp. 10–16, January, 1897.

WALDEYER, W. [Remarks on *Pithecanthropus*] Verh. Berl. Gessellsch. Anthrop., in Zeitschr. für Ethnologie, vol. 27, p. 88, 1895.

Skullcap is so like that of the gibbon that the animal might be referred to a member of the same genus. Femur much like that of a man. No reason to refer the two bones to one individual.

WERTH, E. Der fossile Mensch. 1921. *Pithecanthropus*, pp. 83–119, figs. 36–50.

WEILSER, LUDWIG. Der Pithecanthropus erectus und die Abstammung des Menschen. Verhandl. naturwiss. Vereins in Karlsruhe, vol. 13, Abhandl., pp. 551–576, 1900.

The remains belong together and represent a link between man and the common ape-human stock.

WEINERT, H. Zur Klarung des Pithecanthropus-Problems. Die Umschau, vol. 28, pp. 768–772, Oct. 4, 1924.

Special consideration of the frontal sinus. Conclusion reached that structurally *Pithecanthropus* is nearly intermediate between chimpanzee and man, but that this fact does not indicate genetic intermediateness.

WEINERT, H. Der Affenmensch von Java in neuer Darstellung. Naturwissensch., Berlin, vol. 13, pp. 188–193, 5 figs., 1925.

THE PILTDOWN MAN, EOANTHROPUS

ANTHONY, R. Les restes humains fossiles de Piltdown (Sussex). Revue Anthropologique, vol. 23, pp. 293–306. September, 1913.

AVEBURY, LORD. Prehistoric Times, 7th ed., pp. 1–623, text figs. 1–283. New York and London, 1913.

Piltdown man, p. 337. "The lower jaw, if found by itself, would certainly have been referred to an anthropoid ape. . . ."

BARRELL, JOSEPH. Probable Relations of Climatic Change to the Origin of the Tertiary Ape-Man. The Scientific Monthly, vol. 4, pp. 16–26. January, 1917.

"Most unexpectedly, however, a jaw of a chimpanzee has been unearthed from the Pleistocene of England in association with the Piltdown human cranium, *Homo dawsoni*."

*BIRKNER, F. Die Funde von menschlichen Knochenresten bei Piltdown in Sussex (England). Korr.-Blatt d. Deutsch. Gesellsch. f. Anthrop. Ethnol. u. Urgesch. vol. 44, p. 102. December, 1913.

BOULE, MARCELLIN. La paléontologie humaine en Angleterre. L'Anthropologie, vol. 26, pp. 1–67, figs. 1–21. April, 1915.

BOULE, M. Studies on the Evolution of Primates. L'Anthropologie, vol. 28, pp. 157–159. April, 1917.

Review of Gregory, June 16, 1916. *Eoanthropus*, p. 158. The jaw is that of a chimpanzee.

BOULE, M. The Jaw of Piltdown Man. L'Anthropologie, vol. 28, pp. 433–435, October, 1917.

Review of Miller, 1915. Accepts conclusion that the jaw is that of a chimpanzee.

*BOULE, MARCELLIN. The Piltdown Jaw. L'Anthropologie, vol. 29, pp. 566–568. January, 1920.

Review of Miller, 1918. Declares himself more and more convinced that the skull and jaw pertain to different creatures, a man and an ape.

*BROOM, R. The Evidence Afforded by the Boskop Skull of a New Species of Primitive Man (*Homo capensis*). Anthrop. Papers Amer. Mus. Nat. Hist., vol. 23, pt. 2, pp. 67–79, figs. 1–5, 1918.

"I regard the [Piltdown] jaw as essentially a human jaw * * * the molar teeth are ground down by a transverse movement which is physically impossible for any chimpanzee to accomplish. There does not seem to me the slightest reason why we should hesitate in regarding the jaw as belonging to the same individual as the skull" (p. 78).

* CAMERON, JOHN. A Contribution to the Evolution and Morphology of the Human Skull, Including a Comparative Study of Certain Fossil Hominidae. Trans. Roy. Soc. Canada, ser. 3, vol. 12, pp. 149–183, figs. 1–15, 1918.

DAWKINS, BOYD. [Discussion of the Piltdown skull.] Abstr. Proc. Geol. Soc. London, session 1912–13, pp. 23–24. Dec. 28, 1912. (See also Quart. Journ. Geol. Soc. London, vol. 69, pp. 148–149. March, 1913, issued Apr. 25, 1913.)

Accepts association of skull and jaw. Concludes that *Eoanthropus* is "a missing link between mn and the higher apes, appearing at that stage of the evolution of the higher mammalia in which it may be looked for—in the Pleistocene age. The modern type of man had no place in this age."

DAWSON, CHARLES, and WOODWARD, ARTHUR SMITH. On the Discovery of a Palaeolithic Human Skull and Mandible in a Flint-Bearing Gravel Overlying the Wealden (Hastings Beds) at Piltdown, Fletching (Sussex). Abstr. Proc. Geol. Soc. London, session 1912–1913, pp. 20–22. Dec. 28, 1912.

DAWSON, CHARLES, and WOODWARD, ARTHUR SMITH. On the Discovery of a Palaeolithic Human Skull and Mandible in a Flint-Bearing Gravel Overlying the Wealden (Hastings Beds) at Piltdown, Fletching (Sussex). Quart. Journ. Geol. Soc. London, vol. 69, pp. 117–144, pls. 15–21 (wash drawings; for photographs see Woodward, 1915), figs. 1–10. March, 1913. Read Dec. 18, 1912; issued Apr. 25, 1913.

DAWSON, CHARLES, and WOODWARD, ARTHUR SMITH. Supplementary note on the discovery of a palaeolithic human skull and mandible at Piltdown (Sussex). Quart. Journ. Geol. Soc. London, vol. 70, pp. 82–93, pls. 14–15, figs. 1–3. Apr. 25, 1914.

* DIETRICH, W. O. Neues vom Eoanthropus Dawsoni Smith Woodward. Naturwiss. Wochenschrift, n. F., vol. 15, pp. 714–715. December 10, 1916.

DIXON, A. F. Note on the fragment of the lower jaw from Piltdown, Sussex. Nature, vol. 99, p. 399. July 12, 1917. (Abstract of paper read before Royal Dublin Society, June 26, 1917.)

ELLIOT, G. F. SCOTT. Prehistoric Man and His Story. London and Philadelphia, 1915, pp. I–XIV, 1–398, 64 illustr. and diagrams.

* FRASSETTO, FABIO. Lezioni di anthropologia, vol. 1, Milano, 1918.

Piltdown man, pp. 340–343. The mandible is regarded (p. 342) as more like that of the orang than the chimpanzee, particularly in the form of the inner side of the symphysis and in that of the ascending ramus.

* FRASSETTO, FABIO. New Views on the "Dawn Man" of Piltdown (Sussex). Man, vol. 27, pp. 121–124, pl. G. July, 1927.

* FREUDENBERG, W. Prähistorische Anthropologie. Neues Jahrb. Mineral., Geol. u. Paläont., 1915, vol. 1, pp. 416–420.

GIUFFRIDA-RUGGERI, V. Dawson (Ch.) e Woodward (A. S.). On the Discovery of a Palaeolithic Skull and Mandible in a Flint-Bearing Gravel Overlying the Wealden (Hastings Beds) at Piltdown, Fletching (Sussex). Arch. Antrop. e Etnol., Firenze, vol. 43, pp. 184–186. 1913.

GIUFFRIDA-RUGGERI, V. La successione e la provenienza delle razze Europee preneolitiche e i pretesi Cro Magnon delle Canarie. Revista Ital. di Paleont., Perugia, vol. 22 (1916), pp. 59–67. Mar. 28, 1917.

*GIUFFRIDA-RUGGERI, V. Unicità del philum umano con pluralità dei centri specifici. Rev. Ital. di Paleont., Perugia, vol. 24, pp. 1–15. 1918.

Eoanthropus especially (pp. 11–12). Concludes that the jaw should be treated as that of an ape.

*GIUFFRIDA-RUGGERI, V. La controversia sul fossile di Piltdown e l'origine del philum umano. Monitore Zool. Ital., vol. 30, pp. 7–18. 1919.

GREGORY, WILLIAM KING. The Dawn Man of Piltdown, England. Am. Mus. Journal, vol. 14, pp. 189–200, figs. I–II. May, 1914.

GREGORY, WILLIAM KING. Studies on the Evolution of the Primates, parts 1 and 2. Bull. Amer. Mus. Nat. Hist., vol. 35, pp. 239–355. June 16, 1916.

GREGORY, WILLIAM KING. Note on the Molar Teeth of the Piltdown Mandible. Amer. Anthrop., n. s. vol. 18, pp. 384–387, fig. 47. July–September, 1916.

*GREGORY, WILLIAM KING, and HELLMAN, MILO. The Crown Patterns of Fossil and Recent Human Molar Teeth and Their Meaning. Nat. Hist., vol. 26, pp. 300–309, figs. 1–9, May–June, 1926.

Photographs of Piltdown jaw and teeth, figs. 5, 6. Jaw accepted as human. Of the teeth it is remarked that "the crown pattern of the Piltdown molars . . . is identical with that of all the known species of extinct apes named *Dryopithecus* and allied genera from the Miocene of Europe and India" (p. 305).

*HOLLISTER, N. International Zoology and the International Code. Science, n. s., vol. 48, pp. 12–13. July 5, 1918.

Discussion of the Piltdown jaw shows that authors who do not follow the International Code use no less than three generic names for the chimpanzees.

HOOTON, E. A. The Evolution of the Human Face and its relation to Head Form. Dental Cosmos, vol. 58, pp. 272–281. March, 1916.

Piltdown skull (pp. 277–278) accepted as ". . . an entirely human braincase . . . and paradoxically enough associated with it a long, narrow, and very simian jaw."

HRDLIČKA, A. The Most Ancient Skeletal Remains of Man. Ann. Rep. Smiths. Inst., 1913, pp. 491–552. 1914; Eoanthropus, pp. 501–509, pls. 5–8.

*HRDLIČKA, A. The Piltdown Jaw. Amer. Journ. Phys. Anthrop., vol. 5, pp. 337–347. December, 1922.

*HRDLIČKA, A. Dimensions of the First and Second Lower Molars with their Bearing on the Piltdown Jaw and on Man's Phylogeny. Journ. Phys. Anthrop., vol. 6, pp. 195–216. May, 1923.

*HUNTER, JOHN I. New Light on the Controversy of the Piltdown Jaw and Cranium. pp. 1–11. 1924? Separate from? (Summary of address given before the Soc. Dent. Sci. N. S. W.)

*JIJON, J. y CAAMAÑO. The Piltdown Jaw. Bol. Soc. Ecuatoriana Estud. Hist. Amer., Quito, vol. 1, pp. 184–185. September, 1918.

JOHNSTON, H. H. [Review of Osborn's Men of the Old Stone Age.] The Geographical Journal, vol. 48, pp. 349–350. October, 1916.

Remarks that the author ". . . seems . . . to be a little perverse in quoting the absurd suggestion . . . that the Piltdown jaw and teeth do not belong to the Piltdown calvarium. . . ."

KEITH, A. Ape Man or Modern Man? The Two Piltdown Skull Reconstructions. Illustrated London News, vol. 143, p. 245, figs. 1–6. Aug. 16, 1913.

KEITH, A. [Discussion of new reconstruction of skull of *Eoanthropus*.] Abstr. Proc. Geol. Soc. London, session 1913–14, p. 30. Dec. 31, 1913. (See also Quart. Journ. Geol. Soc. London, vol. 70, p. 98, Apr. 25, 1914.)

KEITH, A. The Significance of the Discovery at Piltdown. Bedrock, vol. 2, pp. 435–453, figs. 1–3. January, 1914.

KEITH, A. The Reconstruction of Fossil Human Skulls. Journ. Royal Anthrop. Inst. Gt. Brit. and Ireland, vol. 44 pp. 12–31, figs. 1–16. January-June, 1914.

KEITH, A. The Antiquity of Man. New Edition, 1925.

Eoanthropus, pp. 486–709.

*KLEINSCHMIDT, O. Realgattung *Homo Sapiens* (L.) Eine naturgesch. Monogr. des Menschen. Berajah, Zoogr. infinita, 1922, pp. 1–30.

Homo sapiens dawsoni (pp. 7–9). The cast of the mandible clearly shows the horseshoe-shaped form of the human jaw (p. 8).

LANKESTER, RAY. [Discussion of the Piltdown Skull.] Abstr. Proc. Geol. Soc. London, session 1912–13, pp. 22–23. Dec. 28, 1912. (See also Quart. Journ. Geol. Soc. London, vol. 69, pp. 147–148. March, 1913. Issued Apr. 25, 1913.)

LANKESTER, RAY. The Missing Link. Diversions of a Naturalist, ch. 30 (pp. 275–291), figs. 24–30 (mostly after Woodward); preface dated June 16, 1915. (Previously published in London Telegraph.)

"The Piltdown jaw is the most startling and significant fossil bone that has ever been brought to light . . . because this jaw and the incomplete skull found with it really and in simple fact furnish a link—a form intermediate between the man and the ape" (p. 284).

*LENOIR, ERNEST-ROBERT. L'Homme et le gibbon. Rev. Anthrop., vol. 36, pp. 427–460. December, 1926.

*LULL, RICHARD SWAN. Organic Evolution, a Text-Book, pp. I–XVIII, 1–729, pls. I–XXX, figs. 1–253. New York, 1917.

Piltdown man, pp. 681–682. Accepts dissociation of jaw from skull. Uses name *Homo dawsoni* for former (fig. 251) and *Pan vetus* for latter (fig. 248).

LYNE, W. COURTNEY. The Significance of the Radiographs of the Piltdown Teeth. Proc. Roy. Soc. Medicine, London, vol. 9, Odont., pp. 33–51, 60–61, figs. 1–7. February, 1916.

MATTHEW, W. D. Recent Progress in Vertebrate Paleontology. Science, n. s. vol. 43, pp. 103–110 (with Eastman, C. R., and Gregory, W. K.). Jan. 21, 1916.

MATTHEW, W. D. Note on the Association of the Piltdown Skull and Jaw. Bull. Amer. Mus. Nat. Hist., vol. 35, pp. 348–350, June 16, 1916.

"But the argument from association is quite too slight to outweigh any . . . contrary evidence, and certainly not adequate to base on it the erection of a new type of primate combining characters hitherto found dissociated in district generic types" (p. 350). (See Smith, May 25, 1916, and Woodward, February, 1916.)

MILLER, GERRIT S., JR. The jaw of the Piltdown man. Smithsonian Misc. Coll., vol. 65, No. 12, pp. 1–31, pls. 1–5. Nov. 24, 1915.

MILLER, GERRIT S., JR. The Piltdown jaw. Amer. Journ. Phys. Anthrop., vol. 1 (January-March, 1918), pp. 25–52, pls. 1–4. July 9, 1918.

MOIR, J. REID. Pre-Palaeolithic Man in England. Science Progress, vol. 12, pp. 465–474, January, 1918.

Piltdown individual, pp. 470–474. "Thus we find in this unique fossil a combination of human [cranial] and simian [mandibular] characters, such as have been looked for by evolutionists ever since Darwin first enunciated his famous theory regarding the ancestry of modern man" (p. 470).

*MOLLISON, TH. Die Abstammung des Menschen. Die Naturwissenschaften, vol. 9, pp. 128–140. Feb. 25, 1921.

Eoanthropus, p. 137–138. Skull and jaw do not belong together.

* MOLLISON, TH. Neuere Funde und Untersuchungen fossiler Menschenaffen und Menschen. Zeitschrift für die gesammte Anatomie, Abt. 3, Ergebn. der Anat. u. Entwicklungsgesch. vol. 25, pp. 696–771. 1924.

Eoanthropus, pp. 715–724. Reviews (imperfectly) literature to date, and concludes that jaw and skull do not belong together and that a chimpanzee-like animal might have lived in Europe during one of the interglacial periods.

* O'DONOGHUE, C. H. [Review of Tull [=Lull], Organic Evolution.] Science Progress, vol. 13, pp. 162–163. July, 1918.

"[The Piltdown jaw] is utterly unlike that of any chimpanzee, as a brief examination of the actual specimen will show. If the jaw does not belong with the skull . . . we have a jaw of an entirely new genus of anthropoids" (p. 162).

OSBORN, HENRY FAIRFIELD. Men of the Old Stone Age, pp. I–XXVI. 1–545. pls. 8, text figs. 268. November, 1915.

Eoanthropus, pp. 130–144. The Piltdown race represents a side branch of the human family which has left no descendants at all (p. 144).

OSBORN, HENRY FAIRFIELD. Review of the Pleistocene of Europe, Asia, and Northern Africa. Ann. New York Acad. Sci., vol. 26, pp. 215–315. July 31, 1915.

OSBORN, HENRY FAIRFIELD. Men of the Old Stone Age, 2d edition. February, 1916.

Eoanthropus, pp. 130–144, 512. Accepts the conclusion that the jaw is that of a chimpanzee.

* OSBORN, HENRY FAIRFIELD. The Dawn Man of Piltdown, Sussex. Natural History, vol. 21, pp. 577–590, figs. 1–15. February, 1922.

Returns to the view that the jaw is human.

* OSBORN, H. F., and GREGORY, W. K. The Dawn Man (an authorized interview). McClure's Magazine, vol. 55, No. 1, pp. 19–28. March, 1923.

PILGRIM, GUY E. New Siwalik Primates and Their Bearing on the Evolution of Man and the Anthropoidea. Rec. Geol. Surv. India, vol. 45, pp. 1–74, pls. 1–4, figs. 1–2.

Accepts association of skull with jaw and places *Eoanthropus* on line leading to *Homo neanderthalensis.* (See Keith, 1915, and Sutcliffe.)

* PILGRIM, GUY E. A *Sivapithecus* Palate and Other Primate Fossils from India. Palaeont. Indica, n. s., vol. 14, pp. 1–24, pl. 1. 1927.

It would appear that the symphysis of both *Eoanthropus* and the Heidelberg jaw are in some ways intermediate between the Haritalyanger jaw [*Sivapithecus himalayensis* Pilgrim] and that of the chimpanzee.

PUCCIONI, NELLO. Appunti intorno al frammento mandibolare fossile di Piltdown (Sussex). Archivio per l'Antropologia e la Etnologia, vol. 43, pp. 167–175. 1913.

PYCRAFT, W. P. Ape Man or Modern Man? The Two Piltdown Skull Reconstructions. The Case for Dr. A. Smith Woodward's Reconstruction. Illustrated London News, vol. 143, p. 282. Aug. 23, 1913. Four figures.

PYCRAFT, W. P. The Jaw of the Piltdown Man—a Reply to Mr. Gerrit S. Miller. Science Progress, vol. 11, pp. 389–409, figs. 1–4. January, 1917.

* PYCRAFT, W. P. Discussion [of paper by Woodward]. Quart. Journ. Geol. Soc. London, vol. 73, p. 9. Apr. 6, 1918.

* RAMSTRÖM, MARTIN. Om underkäken i Piltdown fyndet ("Eo-anthropus"). Svenska Läkaresällskapets Handlingar, vol. 42 (1916), pp. 1223–1256, figs. 1–6. (German synopsis, pp. 1255–6.)

*RAMSTRÖM, MARTIN. Der Piltdown-Fund. Bull. Geol. Inst. Upsala, vol. 16, pp. 261–304, figs. 1–12, 1919.

*RAMSTRÖM, MARTIN. Der Java-Trinil-Fund "*Pithecanthropos*" oder können die "*Eoanthropos*"- und "*Pithecanthropos*"- Funde uns zuverlässige Aufschlüsse über die Anthropogenesis geben? Upsala Läkareförenings Förhandl., N. F., vol. 26, Festskr. Prof. J. Aug. Hammar, art. 29, pp. 1–37. 1921.

RUTOT, A. Quelques découvertes récentes relatives aux races humaines primitives. Bull. Soc. Belge Geol., Proc.-Verb., vol. 27, pp. 5–6. 1913.

SCHWALBE, G. Kritische Besprechung von Boule's Werk: "L'Homme fossile de la Chapelle-aux-Saints." Zeitschr. für Morphologie und Anthropologie vol. 16, pp. 227–610. Jan. 31, 1914.

Piltdown skull and jaw, pp. 603–4. Not willing to accept the suggestion that skull and jaw did not beloing to one individual, but considers the facts too uncertain to form basis of positive opinion.

*SCHWALBE, G. Die Abstammung des Menschen und die älteren Menschenformen. Die Kultur der Gegenwart, pt. 3, sect. 5, Anthropology, pp. 223–336. 1923.

SERA, G. L. Un preteso *Hominida* miocenico: *Sivapithecus indicus*. Natura, vol. 8, pp. 149–173. 1917.

Eoanthropus, pp. 170–171. Accepts association of jaw with skull. The teeth, on account of their height, would perhaps be better compared with those of a primitive *Dryopithecus* than with those of a chimpanzee.

SERGI, G. La mandibola umana. Revista di Antropologia, Roma, vol. 19, pp. 119–168, numerous text figs. 1914.

SERGI, G. L'Evoluzione organica e le origini umane, pp. I–XXII, 1–240. Torino, 1914. *Eoanthropus*, pp. 192–198 and note on p. 236.

Accepts association of skull with jaw, and concludes that the form of the mandible is enough to make the Piltdown man a new type, a new branch, and therefore a new genus.

*SERGI, G. Problemi di scienze contemporanea (Nuova serie). Chapter entitled "Paleantropologia," 1916.

Eoanthropus, pp. 111–117. The teeth are human; the symphsial region of the mandible has a form which is neither human nor anthropoid. The skull and jaw belonged to one individual, and the genus *Eoanthropus* is valid.

SMITH, G. ELLIOT. Appendix [to paper by Dawson and Woodward]. Abstr. Proc. Geol. Soc. London, session 1912–13, p. 22. Dec. 28, 1912.

SMITH, G. ELLIOT. Preliminary Report on the Cranial Cast [of Piltdown skull]. Quart. Journ. Geol. Soc. London, vol. 69, pp. 145–147. March 1913. Issued Apr. 25, 1913.

SMITH G. ELLIOT. The Piltdown Skull. Nature, vol. 92, p. 131. Oct. 2, 1913.

SMITH, G. ELLIOT. The Controversies Concerning the Interpretation and Meaning of the Remains of the Dawn Man Found Near Piltdown. Nature, vol. 92 pp. 468–469. Dec. 18, 1913.

SMITH, G. ELLIOT. The Controversies Concerning the Interpretation and Meaning of the Remains of the Dawn Man Found Near Piltdown. Mem. and Proc. Manchester Lit. and Philos. Soc., vol. 59, pp. VII–IX. Mar. 31, 1914.

"That the jaw and cranial fragments . . . belonged to the same creature there had never been any doubt on the part of those who have seriously studied the matter" (p. VIII). The author believes that "When man was first evolved the pace of evolution must have been phenomenally rapid." He alludes to "the turmoil incident to the inauguration of the Pleistocene Period" (p. IX).

SMITH, G. ELLIOT. Man of the Dawn. Sydney Morning Herald, July 3, 1914, p. 9.

". . . if that [Piltdown] jaw had been found without any teeth, or if it had been found separate from the skull, no one would have hesitated to call it an ape's jaw." (See Smith, 1917.)

SMITH, G. ELLIOT. Discussion [of a paper by Lyne]. Proc. Roy. Soc. Medicine, London, vol. 9, Odont., pp. 56–58. February, 1916.

"To bring a hitherto unknown ape into England in the Pleistocene period involves an upheaval of paleontological teaching."

SMITH, G. ELLIOT. New phases of the Controversies Concerning the Piltdown Skull, Proc. Manchester Lit. and Philos. Soc., vol. 60, pp. XXVIII–XXIX. May 25, 1916.

"In considering the possibility that more than one hitherto unknown ape-like man or man-like ape expired in Britain side by side in the Pleistocene period and left complementary parts the one of the other, the element of improbability is so enormous as not to be set aside except for the most definite and positive anatomical reasons. The author . . . emphasized the fact that the skull itself revealed certain features of a more primitive nature than any other known representatives of the human family" (p. XXIX). (See Matthew, June 16, 1916.)

SMITH, G. ELLIOT. "Man of the Old Stone Age." Amer. Mus. Journ., vol. 16, pp. 319–325. May, 1916.

Review of Osborn. Piltdown skull, pp. 321–322. "But the acceptance of the view that the jaw is an ape's and the cranium a man's would involve the supposition that a hitherto unknown and extremely primitive apelike man, and an equally unknown manlike ape, died on the same spot, and that one of them left his skull without the jaw and the other his jaw without the skull. Not only so, but it would involve also the admission that an anthropoid ape was living in England in middle Pleistocene times. . . ."

SMITH, G. ELLIOT. The Problem of the Piltdown Jaw: Human or Subhuman? Eugenics Review, vol. 9, p. 167, July, 1917.

Review of Pycraft, 1917. "By means of the large collection of data relating to details of the anatomy of the teeth and jaws of chimpanzees and men he has proved quite conclusively that the Piltdown jaw . . . belonged to a primitive member of the human family . . ." (See Smith, July 3, 1914, and Boule, 1920.)

SOLLAS, W. J. Ancient Hunters and their Modern Representatives. Ed. 2, London, 1915, pp. I–XIV, 1–591, 314 figs.

Piltdown man, pp. 49–56. "Some have regarded such a being as an improbable monster and have suggested that the jaw may not have belonged to the skull, but to a true ape. The chances against this are, however, so overwhelming that the conjecture may be dismissed as unworthy of serious consideration. Nor on reflection need the combination of characters presented by *Eoanthropus* occasion surprise. It had, indeed, been long previously anticipated as an almost necessary stage in the course of human development" (p. 54).

SPURRELL, H. G. F. Modern Man and His Forerunners, pp. I–XXII, 1–192, pls. 1–5, text fig. 1. London, 1917.

Piltdown man, p. 44 and pl. 5. "The Piltdown man, though by far the most apelike human remains yet found, has much in common with modern man . . . while he certainly has no place in the direct line of Neanderthal man's descent."

SUTCLIFFE, W. H. A criticism of some modern tendencies in prehistoric anthropology. Mem. and Proc. Manchester Lit. and Philos. Soc., vol. 57, no. 7, pp. 1–25, pls. 1–2. June 25, 1914.

SYMINGTON, J. On the Relations of the Inner Surface of the Cranium to the Cranial Aspect of the Brain. Edinburgh Medical Journal, vol. 14, pp. 85–100, figs. 1–21, February, 1915.

"It is unfortunate that the facts they [endocranial casts of prehistoric skulls] reveal are so few in number and so lacking in precision, but it is surely better to admit frankly the limitations of our knowledge than to reconstruct primitive brains on such slender data" (p. 100).

SYMINGTON, J. Endocranial Casts and Brain Form: A Criticism of Some Recent Speculations. Journ. Anat. and Physiol., vol. 50, pp. 111–130. January, 1916.

Concludes: "That the simplicity or complexity of the cerebral fissures and convolutions cannot be determined with any degree of accuracy from endocranial casts, even on complete skulls, much less on reconstructions from imperfect skulls" (p. 130).

THACKER, A. G. The Significance of the Piltdown Discovery. Science Progress, vol. 8, pp. 275–290. October, 1913.

*TOLDT, C. Ueber den vorderen Abschnitt des menschlichen Unterkiefers mit Rücksicht auf dessen anthropologische Bedeutung. Mitth. Anthrop. Gesellsch. Wien, vol. 45, pp. 248–249. 1915.

TOMES, CHARLES S. A Manual of Dental Anatomy, ed. 7, pp. I–VI, 1–616, figs. 1–300. 1914.

Eoanthropus, pp. 586–588. "There is doubt whether it is justifiable to create a new genus for this man . . . hence . . . the name should be rather *Homo piltdownensis*" (p. 586). "The contour of the front of the mandible is exactly that of a young chimpanzee. The [molar] teeth, however, are quite human" (p. 586).

UNDERWOOD, ARTHUR S. The Piltdown Skull. British Journal of Dental Science, vol. 56, pp. 650–652, 3 plates (not numbered). Oct. 1, 1913.

*VIRCHOW, HANS. Zahnbogen und Alveolarbogen. Zeitschr. für Ethnologie, vol. 48, pp. 277–295. 1916.

WALKHOFF, Dr. Entstehung und Verlauf der phylogenetischen Umformung der menschlichen Kiefer seit dem Tertiar und ihre Bedeutung für die Pathologie der Zähne. Deutsche Monatsschr. für Zahnheilkunde, vol. 31, pp. 947–979, figs. 1–9. December, 1913.

Piltdown jaw (pp. 971–979). Accepts association of skull and jaw. Regards the jaw as a confirmation of his views on the origin of the chin.

WATERSTON, Prof. [Discussion of the Piltdown skull.] Abstr. Proc. Geol. Soc. London, session 1912–13, p. 25. Dec. 28, 1912. (See also Quart. Journ. Geol. Soc. London, vol. 69, p. 150. March, 1913. Issued Apr. 25, 1913.)

WATERSTON, DAVID. The Piltdown Mandible. Nature, vol. 92, p. 319, figs. 1–3, Nov. 13, 1913.

Compares with chimpanzee and concludes that " . . . it seems to me to be as inconsequent to refer the mandible and the cranium to the same individual as it would be to articulate a chimpanzee foot with the bones of an essentially human thigh and leg."

* WERTH, E. Die Auflösung des Eoanthropus Dawsoni. Zeitschr. für Ethnologie, vol. 48, pp. 261–264. 1916.

* WERTH, E. Das Problem des tertiaren Menschen. Sitzungsber. Gesellsch. naturforsch. Freunde zu Berlin, 1918, pp. 1–32, figs. 1–9. *Eoanthropus*, pp. 21–26. Apr. 30. 1918.

*WERTH, E. Der fossile Mensch. 1921. *Eoanthropus*, pp. 803–808, fig. 640.

WOODWARD, A. SMITH. The Piltdown Skull. Brit. Med. Journ., vol. 2 for 1913, p. 762. Sept. 20, 1913.

WOODWARD, A. SMITH. The Piltdown Skull. Nature, vol. 92, pp. 110–111. Sept. 25, 1913.

WOODWARD, A. SMITH. Note on the Piltdown Man (*Eoanthropus dawsoni*). Geol. Mag. n. s., Dec. 5, vol. 10, pp. 433–434, pl. 15. October, 1913.

WOODWARD, A. SMITH. A Guide to the Fossil Remains of Man in the British Museum, pp. 1–33, pls. 1–4 (photographs), figs. 1–12. 1915.

WOODWARD, A. SMITH. Discussion [of a paper by Lyne]. Proc. Roy. Soc. Medicine, London, vol. 9, Odont., p. 52. February, 1916.

"It seems to me most improbable—almost incredible—that when we find a unique primate skull in the same place as an absolutely new primate jaw and close to an entirely new primate tooth we are dealing with the remains of three distinct animals." (See Matthew, June 16, 1916.)

* WOODWARD, A. SMITH. Fourth Note on the Piltdown Gravel, with Evidence of a Second Skull of *Eoanthropus dawsoni*. With an Appendix by Prof. Grafton Elliot Smith. Quart. Journ. Geol. Soc., London, vol. 73, 1917, pp. 1–10, pl. 1, figs. 1, 2. Apr. 6, 1918.

* WOODWARD, A. SMITH. Presidential Address. Proc. Linn. Soc. London, pp. 27–34, 1923.

Diagram on page 30 to show "that if the milk dentition of modern man were modified by the complete extrusion of the canines this would resemble the permanent dentition of the Piltdown fossil man more closely than does the permanent dentition of any ape."

ADDENDA

Too late to use it in the body of the text I have seen the following book in which both of the "missing links" have been given a new interpretation—namely, that they are the remains of African negroes, migrants from the Nile region.

CHURCHWARD, ALBERT. Origin and Evolution of the Human Race, pp. I–XV, 1–511, pls. 1–77, London, 1922.

"*Pithecanthropus* was a pigmy [African] . . . Personally I have not the slightest doubt that the Piltdown skull [and jaw] belonged to a Non-Hero Cult Nilotic Negro" (pp. 26, 499).

The following reference was omitted from its proper place on page 448:

* DRENNAN, M. R. A Contribution to the Piltdown Problem. Nature, vol. 120, p. 874, 1 text fig., Dec. 17, 1927.

By a new system of calculation the capacity of the brain case is determined as 1415 cc.

WHAT IS KNOWN OF THE MIGRATIONS OF SOME OF THE WHALEBONE WHALES

By Remington Kellogg
Division of Mammals, United States National Museum

[With two plates]

Some of the living cetaceans are great travelers and apparently wander at will over the Atlantic and Pacific Oceans, while others pursue a fairly definite route at stated intervals. Some may appear off the coasts of two or more continents in the course of their migrations, while others follow but one coast on their northward and southward runs. In the South Atlantic, humpbacks, finbacks, and blue whales frequent the icy waters off the Antarctic Continent during the southern summer and migrate northward along the coasts of South America and Africa in the fall and winter. In the North Atlantic some of the humpbacks and finbacks seem to follow the North American coast for some distance on their northward run past the islands off the European coast. There are a few whales which exhibit decided preferences for definite areas, while others apparently travel where they will. The bowhead (*Balæna mysticetus*), which frequents the Arctic seas, and the pigmy whale (*Neobalæna marginata*) of New Zealand waters are restricted to limited oceanic areas. The extent of the migrations of some whales is largely a matter of conjecture, but the evidence points to the conclusion that an occasional individual or school travels from the South Pacific to the North Pacific and vice versa. Sei whales have been taken in Japanese waters with ectoparasites of South Pacific origin according to Andrews (1916, pp. 322, 331). Information from other sources indicates that whales may occasionally pass from one ocean to another south of Cape Horn and Cape of Good Hope. It is quite likely that there may be an interchange or intermingling of individuals in the herds that pass the Antarctic summer in the Strait of Bransfield, for this latitude is the feeding ground of those that migrate southward along the Atlantic and Pacific coasts of South America. The presumption is that these newcomers will later accompany their respective schools northward to the calving grounds and to the summer home of those particular whales.

The possibilities for wide dispersal of cetaceans are exceptionally great, in view of the absence of physical barriers, and apparently the chief controlling factor is the food supply. Hence it may appear rather surprising that some of the larger whales, such as the gray whale, the humpback, and the bowhead, should follow definite routes in their migrations. The kind of plankton eaten by whalebone whales, according to Bigelow (1926, p. 99), is largely determined by the fineness of their straining apparatus. This consists of a row of contiguous blades of baleen hanging downward from the roof of the mouth on each side. These blades of baleen have internal marginal fringes of intermatted bristlelike fibers which function as a sieve when the animal is feeding and thus prevent the egress of plankton too large to pass through the interspaces with the outrush of water when the mouth is closed. Mysticetes with coarse comblike whalebone, such as the finback, the blue whale, and the humpback, can capture the large euphausids, but the smaller calanids escape with the outpouring water. The unusually fine bristles of the sei whale and the North Atlantic right whale sift out the smaller calanid copepods as well as the larger shrimplike euphausids. But whales with coarse-fringed whalebone seem to be much more adept in capturing fish than those with fine-fringed whalebone.

Some of the whalebone whales consume enormous quantities of these euphausids, and on the Antarctic whaling grounds most of them feed almost exclusively upon these minute crustaceans. Even the blue whale, the largest mammal that has ever lived, seems to be dependent upon such small prey. Prof. G. O. Sars found that the stomach contents of a blue whale taken in the Norwegian Sea consisted chiefly of a small shrimplike crustacean (*Thysanoessa inermis*), and Collett (1877, p. 161) reports that occasionally one is taken that has eaten nearly 1,200 liters of Thysanoessa. The shrimplike Thysanoessa and Meganyctiphanes in the North Atlantic and Euphausia in the Antarctic seem to constitute the bulk of the food of the blue whale. The food of finbacks may vary according to local conditions, for the stomach of one (Cornwall, 1928, p. 11) taken near Vancouver Island was filled with a small squid (*Gonatus fabrici*). Mörch (1911, p. 666) has pointed out that the distribution of finbacks in the North Atlantic depends upon the seasonal appearance of plankton, capelan (*Mallotus villosus*), and herrings. Bryde's whale (*Balænoptera brydei*) does not seem to be wholly dependent upon the occurrence of euphausids according to Olsen (1913, p. 1085), as it is generally seen near the shore feeding on fish, such as herring and mackerel, but in one instance sharks over 2 feet in length were found in a stomach, and in another case no less than 15 penguins (*Spheniscus demersus*) and "malagass" (*Sula capensis*). The same writer states that copepods (Calanidæ) are the chief source of

food for the sei whale (*Balænoptera borealis*). The stomach contents of several sei whales (Collett, 1886, p. 261) killed off East Finmark in July consisted entirely of the copepod, *Calanus finmarchicus*, but along West Finmark they were feeding on euphausids. The bowhead often feeds on pelagic mollusks (Lilljebörg, 1866, p. 308) such as the pteropods, *Clio* and *Limacina*, in addition to copepods of the genus *Calanus*.

While the available data seem to indicate that the migrations of whales are governed to some extent at least by the plankton supply and hydrographic changes, their annual journeys take them to localities favorable for reproduction and growth of young. It is also possible that the food prerequisites of any given area may remain favorable, but that the whales for some inexplicable reason have gone elsewhere. The seasonal north and south migrations may also under certain conditions extend east and west. If this is confirmed, the fact will further complicate the study of the biology of these pelagic mammals.

The underlying causes for the marked seasonal fluctuations in the abundance of whales on many of the whaling grounds is little understood at present. By tracing the movements of waters surrounding the feeding grounds of whales it may be possible to discover the physical and biological factors that regulate these fluctuations. Oceanographic investigations have repeatedly shown that there is a direct connection between the physical and biological conditions of the feeding grounds and the presence or absence of pelagic animals. It has been shown that there are certain mass movements of water which may alter any set of conditions. The chemical content of sea water varies from time to time and from place to place according to the influence of ocean currents and ocean drift. Sufficient quantities of certain kinds of food necessary to support the long-continued presence of large numbers of whales require favorable hydrographic conditions. An excellent illustration of the influence of hydrographic factors on the propagation of plankton is brought out by the observations of Hardy (1928, p. 771) in the vicinity of South Georgia.

It is generally accepted that ocean currents result from differences in the specific gravity of water, and that masses of water will flow from the place where it is relatively light to another region where it is proportionately heavy. Prevailing winds, rotation of the earth, and tides also exert an influence on the movement of masses of water. Some of these currents are cold and others warm. Physical differences such as salinity and temperature make oceans a complex of water masses. Observations have shown that there is an upper layer of cold fresh water and a lower layer of salty water at the entrance

24034—29——31

to the Baltic. Subtropical seas, as, for instance, the Red Sea and the Persian Gulf, have water above the normal salinity, while Hudson Bay and the Baltic Sea are below normal in salinity.

The Gulf Stream in the North Atlantic undergoes a periodical expansion and contraction, and the flooding which accompanies these gigantic pulsations periodically influences hydrographic conditions in the waters bordering northern Europe. The maximum flooding of the North Atlantic by the Gulf Stream, according to Jenkins (1921, p. 75), occurs in August. The ice-chilled Nova Scotian current which floods westward into the Gulf of Maine every spring is an overflow of the pool that develops from Cabot Strait out over Banquereau Bank with the melting of field ice from the Gulf of St. Lawrence, and this surface drift, which flows past Cape Sable into the Gulf of Maine, originates some 300 miles eastward. (Bigelow, 1927, pp. 681, 832.) Between Cape Sable and Cape Cod the surface water is chilled to its minimum for the year in the last week of February and the first few days of March. At this time the surface temperature of the coastal belt is as low as 35.6°, while the central and offshore reaches 36.5° and 38.3° F. In mid-August the surface readings may reach 68° F. During the month of February the surface temperatures of the Irish Sea range from 40.6° to 46.7° F. and in August from 55.6° to 62.2° F. (Jenkins, 1921, pp. 64–65.) According to the chart of isotherms of surface temperatures prepared by Fowler (1912, chart 4), the surface temperature of the Caribbean Sea is 80.6°, the Mediterranean 62.6° to 69.8°, Gulf of Biscay 59°, Norwegian coast 48.2° to 41°, Iceland 41° to 42.8°, and Spitzbergen 32° to 30.2° F.

From these data it would appear that neither salinity nor temperature by themselves interpose any appreciable barrier to the migration routes of whales, for in the North Atlantic whales leave the Caribbean Sea with its surface temperature of 80° F. and journey northward toward Greenland waters, where the surface temperatures of the water range from 32° to 30.2° F. On the North American side they enter water chilled by pack ice and icebergs issuing from Davis Strait, and on the European side they reach the icy waters in the vicinity of Spitzbergen. These physical factors, however, do indirectly determine to some extent the migration routes of whales, for unless hydrographic conditions are favorable plankton will be too scant to feed the animals that are dependent upon it for their sustenance. The Gulf Stream is bounded on the left by cold water, the temperatures of which are reported to be from 50° to 57° below that of the Gulf Stream. Favorable conditions for growth of plankton are created where the cold polar current mixes with water of higher temperature. And it is along the border layers of these great currents of icy water that the produc-

tion of plankton reaches its maximum wherever there is a sufficient actinity of light, nutritive salts, and an intermingling with warmer currents.

Vegetation is the ultimate source of food for pelagic animals, and plants are dependent for their existence in part upon sunlight to assimilate carbon and in part on the presence of certain nutritive solutions of salts. Sea water of low temperature has a somewhat higher gaseous content and is richer in nitrogenous compounds. By synthesis of water and carbonic acid under a certain actinity of light the microscopic plants that obtain their food directly from inorganic substances in sea water are able to combine elementary nitrogen salts with carbohydrate and produce proteids. Microscopic diatoms form the bulk of the vegetation of the colder seas, and they float at or near the surface. Microscopic animals known as peridinians and dinoflagellates are often very abundant. Immense swarms of a small shrimplike crustacean (*Euphausia superba*) make their appearance with the approach of Antarctic spring on the whaling grounds, and these euphausids are dependent upon diatoms for their sustenance. (Kemp, 1928, p. 191.) Euphausids are known to feed on copepods, cladocera, and peridinians, as well as diatoms. The duration of life of plankton varies in accordance with the temperature of the water, and in sea water of low temperature there exists a vastly larger number of coexisting generations than in warm oceans or in shallow coastal waters of low salinity. Hence in Boreal and Antarctic waters there is an astonishing abundance of minute pelagic animals (plankton) in the upper layers during the spring and summer months, and for this reason the whales congregate in these regions at this season of the year. In late fall or early winter, with the chilling of the surface water and descent of their favorite food, many of these whales migrate toward the Tropics.

Information relating to the migrations of whales has been assembled from many sources. Some of these data while suggestive need corroboration, and this is especially true of migration records based on whales from which foreign makes of harpoons have been recovered. There are many instances on record of the finding of harpoons which were readily identifiable as the type employed by whalers operating in other parts of the world. Taking into consideration the extent of the voyages of many of the whaling vessels during the past century, particularly our own New England whalemen, it is obvious that too much stress should not be laid on this sort of evidence. The whalers of the past century had little actual knowledge of the migrations of whales, but they were acquainted with localities where whales were accustomed to appear in considerable numbers at definite seasons, and so planned their voyages that they

could visit one or more of these areas if necessary to complete their cargo.

By plotting the operating seasons on these whaling grounds, the ship logs giving the locations and dates of the whales taken, the records of shore stations giving the time of arrival of the whales in their vicinity, and the observations of experienced whalemen on schools migrating in definite directions, as well as those of naturalists who have given some thought to this problem, we find that there is a surprising amount of evidence bearing on the seasonal north and south migrations of whales to and from their breeding grounds. It is hoped that more accurate information on the extent of the migration of whales will result from the use of disks by the *Discovery* expedition (Kemp, 1928) in the vicinity of South Georgia and that this practice may be extended to other regions.

HUMPBACK (MEGAPTERA NODOSA)

The accumulated evidence indicates that the humpback whales of the northern and southern latitudes undertake migrations along well-

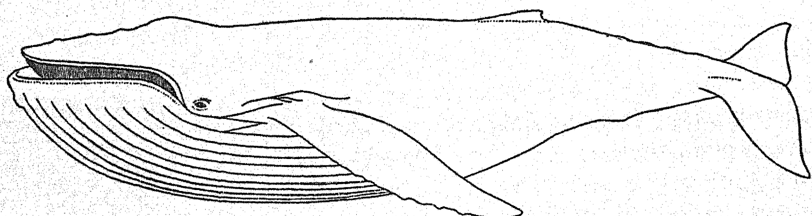
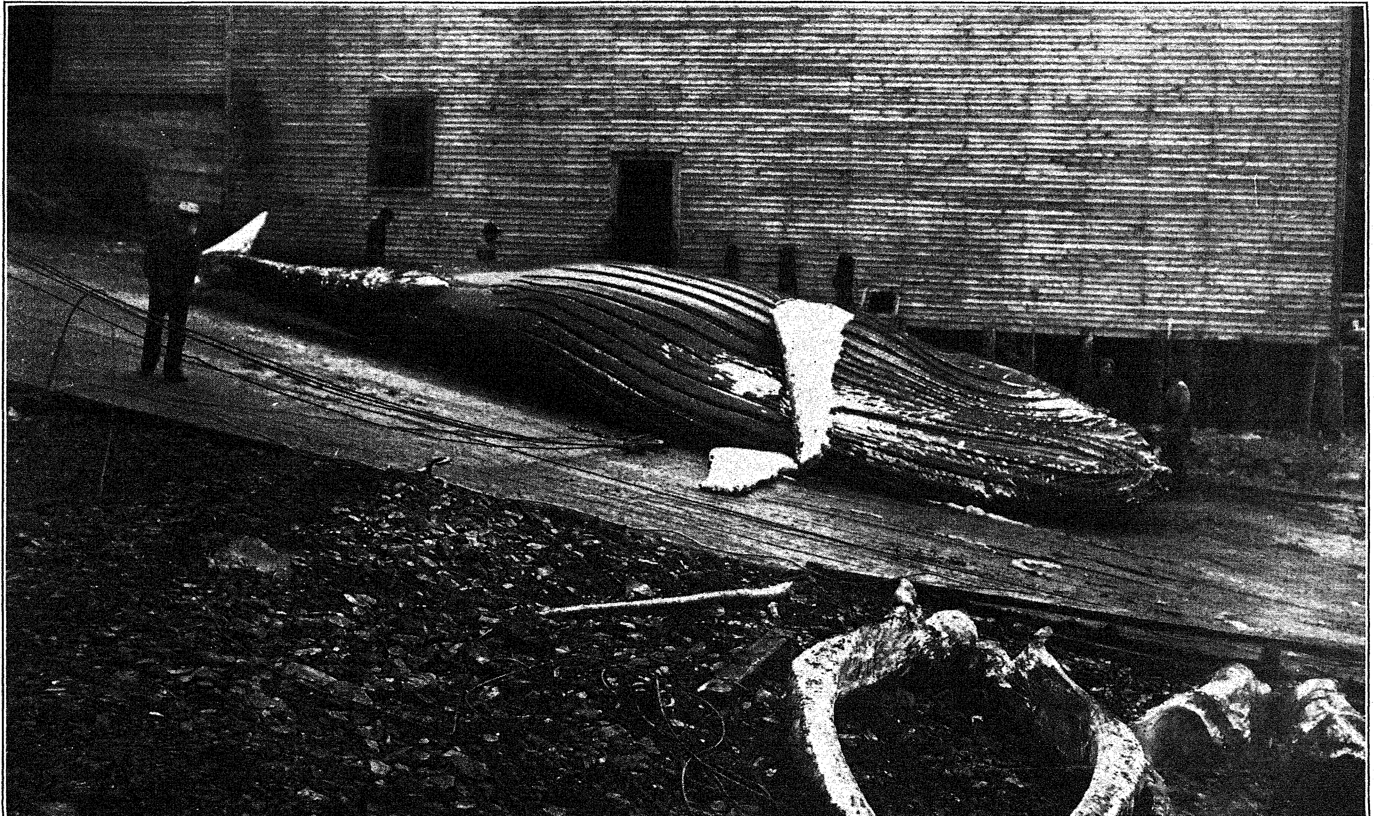


FIGURE 1.—Humpback whale [*Megaptera nodosa* (Bonnaterre)]. Outline drawing. Notice the long fore flipper and the widely spaced throat grooves

defined courses at definite seasons, and this is especially true in southern latitudes. Generally speaking, the southern humpbacks leave the Antarctic polar seas in the autumn, pass the winter in the Tropics, and return to the Antarctics in the spring. The northern humpbacks leave the Tropics in the spring or early summer, journey toward the Arctics before the summer is far advanced, and return southward in late fall or winter. These migrations are rather closely connected with the breeding habits of the species.

Females with calves apparently work their way toward the summer feeding grounds at a much slower rate and arrive somewhat later in the season than bulls and nonbreeding cows. Surprising as it may seem, there is evidence that some of the humpbacks in the North Atlantic may remain in the open Arctic seas through the winter months. Humpbacks journeying westward from the eastern portions of the Arctic Ocean (Risting, 1912, pp. 438, 440) have been observed passing along the coast of Finmark in the months of January, February, and the early part of March. During the same



MALE HUMPBACK (MEGAPTERA NODOSA (BONNATERRE))

Taken by the Cabot Steam Whaling Co. at Snooks Arm Station, Notre Dame Bay, Newfoundland, on August 9, 1899. Length, 42 feet 2 inches

period according to Hinton (1925, p. 89) numbers are found off Bear Island, Jan Mayen, and to the north of Iceland. Nevertheless, the New England whalers were accustomed to hunt for humpbacks in the vicinity of the Cape Verde Islands during the winter months. In April or early spring some of these northern wintering schools may migrate southward to join those that have given birth to calves in the warmer portions of the North Atlantic. From March to May females with new-born calves have been observed in the vicinity of the Azores, the Cape Verde Islands, and off the northwestern coast of Africa. On their northward migration, the hump-

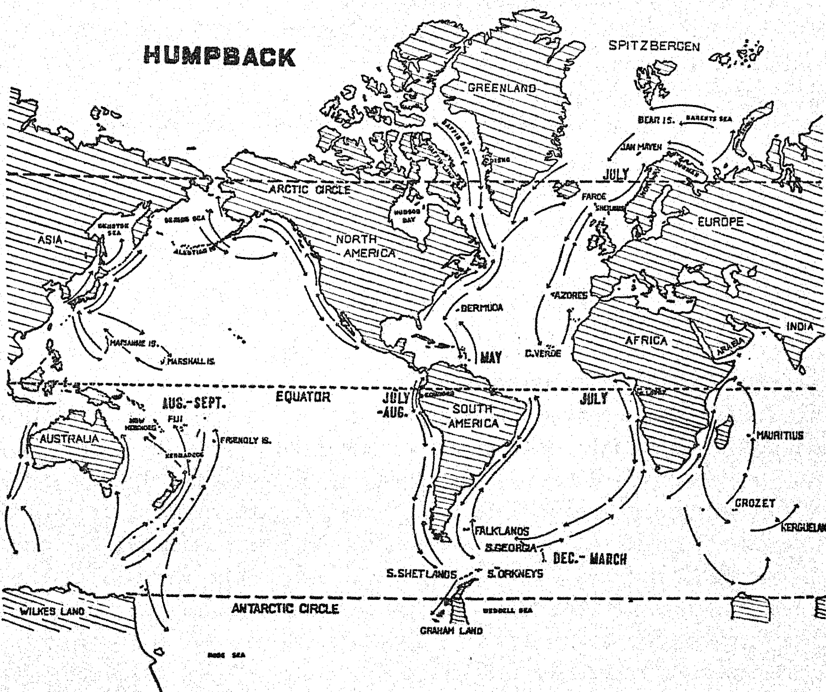


FIGURE 2.—Distribution map for the humpback whale, with supposed migration routes in north and south latitudes

backs pursue a general course from southwest to northeast. In May they are seen approaching the Shetland and Faroe coasts, but large numbers have suddenly appeared at Varangerfjord (Eastern Finmark) as early as February and March. Large herds of humpbacks are often seen in June and July some 60 miles due west of Rona's Voe. (Millais, 1906, p. 236.) Toward autumn, according to Risting (1912, p. 442), the humpbacks move northward toward the seas around Bear Island and below Spitzbergen. Later with the chilling of the surface water and the descent of the capelan, the humpbacks move to the more open parts of the Arctic Ocean, where some pass

the winter months feeding on herring shoals. The pregnant females and some of the others migrate to the Tropics.

On the western side of the North Atlantic there is a surprising frequency of occurrences at unexpected seasons. Depletion in numbers may have made the normal migrating seasons less apparent. Humpbacks with calves have been observed as early as February in the vicinity of Bermuda and the Lesser Antilles. At Barbados, humpbacks sometimes appear as early as January, and the season usually extends from March to May, and all have left by June, according to Lindeman (1880, p. 85). They also occur in the vicinity of Tobago, Grenada, and St. Lucia during the same season. (True, 1904, p. 62.) The early New England whalers were accustomed to find large numbers of humpbacks congregated in the waters in the vicinity of the Island of Trinidad and the Gulf of Para. Available data indicate that those in the Caribbean Sea generally have left it by May.

The northward movement continues until late summer. From Massachusetts to Maine on the New England coast humpbacks first begin to appear on their northward migration in April and are followed by others in May. Large herds of humpbacks "on passage" and moving at a rapid pace have been seen in April some 200 miles east of the North American coast. Humpbacks also have been observed off the New England coast in June, July, and August. Those that have been observed in these waters during the summer months may either be females with calves or stragglers from the main northward migrating schools. Capt. J. W. Collins noticed unusual numbers of northward migrating humpbacks on May 17, 1877, south of Newfoundland in latitude 44° 16′ north and longitude 58° 59′ west. (Clark, 1887, p. 22.) Guldberg states that humpbacks are rarely encountered off Newfoundland in the months January to April, but then they commence to appear. A humpback and its calf were taken in Hermitage Bay, Newfoundland, in June, 1903. (Millais, 1906, p. 238.) Humpbacks occur in the vicinity of Iceland in May and June. It would seem that some of these humpbacks penetrate Davis Strait and Baffin Bay off the Greenland coast (Brown, 1875, p. 84), for they have been taken in Disco Bay in late summer and early autumn, and that they then proceed southward in advance of the drifting ice which issues from Baffin Bay. Large numbers of southward migrating humpbacks were seen by Captain Larsen in September about 70 miles southeast of Cape Farewell. (Millais, 1906, p. 235.) True (1904, p. 111) was informed that humpbacks arrive in large numbers in the vicinity of Snooks Arm, Newfoundland, later in the year than August, and from other sources we learn that they pass Newfoundland on their southward run in late September and October. Southward migration seems to be a gradual process at

present, with those that have ventured farthest north gradually replacing those that have been delayed or those that have pursued a more leisurely journey. Humpbacks have been observed along the New England coast, but well off shore, as late as October, and there is at least one December record for Massachusetts. (Allen, 1916, p. 309.) We have little actual knowledge in regard to the remainder of their southward trip, except that in former years numbers passed through the Charleston whaling grounds.

Two annual movements of humpbacks in southern seas are described by Collett (1912, p. 607) and Risting (1912). They point out that the migration of humpbacks to and from South Georgia each year takes place at definite seasons. Although humpbacks appear first off South Georgia in October, the largest herds arrive in November, December, and January. (Hinton, 1925, p. 90.) Then the humpbacks commence to leave and by the middle of May all have vanished. From May to September they undertake extensive breeding migrations toward the north along South American and South African coasts to warmer oceanic regions near the Equator. Humpbacks occur off the coast of Africa from 3° north latitude to 7° south latitude from June to September. (Clark, 1887, p. 22.) At Saldanha Bay north of Cape Town humpbacks are most abundant at the end of June and in October. Therefore it would seem that these periods mark the height of the northward and southward migrations, respectively. (Hinton, 1925, p. 190.) Humpbacks arrive at Port Alexander, Benguela, early in June, and the majority have passed by the middle of July. The northward run extends from May until the end of July; the return journey extends from the middle of August to the middle of November. The cold northward flowing Benguela current on the west coast of Africa appears to form the only path through the tropical seas to the Equator traversed by these whales, and this cold polar current has an essentially littoral course. Thus the humpbacks go northward for pairing and giving birth to their young. The young are born near Cape Lopez, French Equatorial Africa; the Bay of Biaffra off the Cameroons; and elsewhere to the south off Portuguese West Africa. They again appear off Benguela from August to October. Their return journey is a feeding migration to the subpolar waters, where with the approach of the Antarctic spring in November a rich growth of plankton makes its appearance, the result of a peculiar combination of light and cold of the polar summer. The bulk of the southern humpbacks, according to Collett, are present on the great feeding places of the south polar sea during the summer months, December to March. Humpbacks are distributed from Bransfield Strait south to Matha Bay along the western coast of Graham Land, individuals

having been observed by Liouville (1913, pp. 3, 33–35) off Petermann Island on November 7 and in Matha Bay on January 13, 1909.

Other schools of humpbacks follow the eastern coast of Africa northward past Durban, Inhambane (Mozambique), Angoche Islands, and the Island of Mauritius to the Indian Ocean, but humpbacks have been taken as far north as the southern coast of Arabia and Baluchistan. Females with young have been observed in the warm southward-flowing Mozambique current as early as June and July in the vicinity of Durban. The southward run to the Antarctic regions commences in August, and the last humpbacks are seen off Linga Linga, Inhambane, in October. (Hinton, 1925, p. 190.) They have been taken off Durban as late as November. Some of these humpbacks spend the Antarctic summer south of Crozet and Kerguelen Islands, as there is little or no evidence to suggest that they form part of the herds that congregate in the vicinity of South Georgia. It is nevertheless true that whalers operating off Cape of Good Hope reported seeing humpbacks on a westerly migration. (Hinton, 1925, p. 189.) Humpback whales were seen near the edge of the pack ice in the vicinity of 25° east longitude and 67° south latitude on February 6, 1831, by Biscoe. (Racovitza, 1903, p. 119.)

A somewhat similar migration occurs along the eastern coast of South America. This takes the humpbacks on their northward run through the "Brazil Banks," a favorite whaling ground about 1774, to the tropical waters where the young are born. On the downward run to the Falklands they seem to follow the southward-flowing Brazil current.

From Scammon (1874, p. 43) we learn that he observed during the years 1852 and 1853 that large numbers of humpbacks resorted to the Gulf of Guayaquil, coast of Peru, to calve. The height of the season was during July and August, after which the schools commenced their southward run along the cold northward-flowing Peru current to the South Shetlands and the waters off Graham Land in the Antarctics. Humpbacks formerly were taken all along the coast of Ecuador and Colombia from Guayaquil to the Bay of Panama. The season along Ecuador began in February, and the whaling vessels worked southward until they reached the Gulf of Guayaquil in June.

After spending the summer in the icy waters of the Ross Sea and along the pack ice north of Victoria Land the first humpbacks of the season pass the Bay of Islands, New Zealand, on their northward run about the middle of April. (Lillie, 1915, p. 110.) The bulk of the herds pass this locality in May and in early June. They proceed northward at least as far as the Kermadecs, the Friendly Islands, the Fiji Islands, and the New Hebrides, and bring forth their young in subtropical seas. Humpbacks with calves are found in the vicinity

of the Kermadecs from August to the end of November. (Oliver, 1922, p. 565.) The season on the reefs around the Friendly Islands (174° W. long. and 21° S. lat.) includes August and September. (Scammon, 1874, p. 43.) Then the southward movement begins, and they again occur after the middle of September in small numbers off the Bay of Islands, but the majority pass in October and by the middle of December they occur farther south. (Lillie, 1915, p. 110.) During the Antarctic summer whaling operations for humpbacks are carried on in the vicinity of Campbell Island. Ross (1847, p. 191) reported seeing great numbers of humpback whales in Ross Sea (172° 20′ E. long. and 71° 50′ S. lat.) on January 14, 1841, yet Lillie states that humpbacks do not go farther south than the outskirts of the pack ice.

On their northward run some of the herds of humpbacks pass near Tasmania and along the western coast of Australia and journey as far northward as the Rosemary Islands, 20° 30′ south latitude. Others do not migrate so far north, and the cows have been known to give birth to calves in Geographe Bay on the coast of southwest Australia. Humpbacks are found along the western coast of Australia from June to November and occasionally in December. (Clark, 1887, pp. 22, 208.)

On the American side of the North Pacific numbers of humpback whales with calves a few days old have been observed in December in Banderas Bay, Jalisco, Mexico. (Scammon, 1874, p. 43.) In May, 1855, Scammon (1874, p. 43) reported seeing large numbers of humpbacks, some with large calves and others with smaller ones, at Magdalena Bay, southern Lower California. The humpbacks begin their northward run along the coasts of California in March and April, and continue to work their way northward past Vancouver in May and June, and the Baranoff Islands until as late as September. A young humpback and its mother were killed near Sechart, Vancouver, on June 16, 1908. (Andrews, 1916, p. 73.) Some of these schools feed in the vicinity of the Aleutian Islands in August and September, while others pass through Bering Sea to Bering Strait. Humpbacks have been taken in Bering Sea at least as late as September 17. The northward migration is prolonged into midsummer by occasional stragglers, for small numbers are taken at Eureka, Calif., in June and July. They appear again along the California coasts in late fall on the down run, appearing off the Bay of Monterey from October to November, but the largest numbers pass southern California in the months of December, January, and February. The cows and their calves usually keep well out to sea, but the bulls come closer inshore.

Published data in regard to seasonal migrations of humpbacks along the Pacific coast of Asia are very limited. Whalers formerly

hunted for humpbacks in the vicinity of the Marianne (or Ladrone) Islands and the Marshall Islands during the winter months. We learn from Andrews (1916, p. 77) that humpbacks were observed late in January at the southern end of Formosa, and that others were taken at Oshimi, Japan, in February (Andrews, 1916, p. 60). During the same month humpbacks were observed near Ulsan, Korea. This indicates that some of the migrating whales pass through the Japan Sea to Okhotsk Sea (Bolau, 1895, p. 18) and that others follow the Pacific side of the Japanese Islands to the Kamchatka coast.

In reviewing what has been said it may be noted that the northern herds pass the Arctic Circle to reach their feeding grounds, while the bulk of the southern herds rarely pass the Antarctic Circle on account of the pack ice.

BOWHEAD (BALAENA MYSTICETUS)

Bowheads are migratory animals and change their station according to season. They approach the pole in the summer and appear in

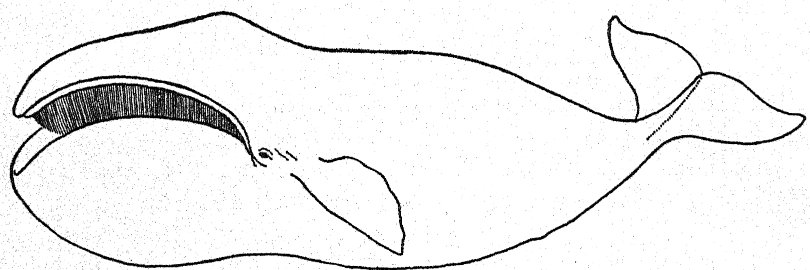


FIGURE 3.—Bowhead or Greenland whale [*Balaena mysticetus* Linnaeus]. Outline drawing. Notice the relatively great size of the head and the absence of throat grooves

the winter near shores where they are never seen during the milder seasons. Formerly their range extended from Spitzbergen westward to eastern Siberia, but the Holland whalers exterminated the bowheads in the Spitzbergen area before 1800. Large numbers of spring migrants coming from the southwest were observed by Dutch sailors who wintered on the Island of Jan Mayen in 1633–34. The first bowheads were seen on March 27, and from then on they were observed daily until the end of April. From Southwell (1898, p. 401) we learn that the migrating bowheads reached Prince Charles Foreland, Spitzbergen, by the middle of May and that they remained in the vicinity until the end of June, when they disappeared for the season in a northwesterly direction. After the middle of June they frequented the seas from 72° to 75° north latitude and 13° west longitude off the east coast of Greenland. During August and early in September the southward migrating bowheads followed the shallow water of the east coast of Greenland. Thus on the east side of Green-

land bowheads were found as far north as the border of the permanent polar pack ice, and in the winter they were found in the vicinity of 65° north latitude.

From Eschricht (1866, p. 15) we learn that bowheads keep close to the ice and remain with ice floes or near solid ice even during the coldest part of the year. They rarely quit the ice edge, and as soon as the ice is disrupted in the spring, they force their way northward through the field ice. The preference of this whale for ice and waters filled with ice floes seems to explain their absence in winter from the ice-free sea south of Sukkertoppen. Bowheads have been met with off the entrance to Hudson Strait and Resolution Island in April, May, or even as late as the middle of June, and as the ice retreats the old males enter Davis Strait on their northward journey to Disco Bay.

The records of the West Greenland whaling stations indicate that females and young were less numerous than males on the northward run, although there were instances where females and young were taken in May and July. This and other data led Southwell (1898, p. 406) to conclude that the females and their young followed the western border of the pack ice in Davis Strait. There seems to be some connection between the wanderings of the bowhead and the motion and drift of the ice in Baffin's Bay. Their arrival on the coast of Greenland is contemporaneous with the arrival of huge masses of drifting ice issuing from Baffin Bay, locally known as "west ice." Some of those that have followed the west Greenland coast are found as far north as Omenak Sound (71° N. lat.) in June. When the land floes have broken up, they cross Baffin Bay to join those that followed the western shore and wait for the breaking up of the ice in Lancaster Sound some time in July. These bowheads spread out over Prince Regent's Inlet and the deep channels intersecting the Northern Archipelago where they spend the summer. Brown (1875, p. 80) reports that "those killed early in the year at Pond's Bay are chiefly young animals." Bowheads have also been met with in the most northerly parts of Baffin Bay (75° to 78° N. lat.) in July and August. Baffin saw many whales at Wolstenholme Sound (78° N. lat.) at the entrance of Smith Sound in July, 1616, and Ross in 1818 met with whales between 75° and 76° north latitude late in July and on August 16.

When the ice begins to form in the fall, the bowheads commence their southward migration and the males generally follow the western shore. (Southwell, 1898, p. 406.) Many of these bowheads have been "running" in Eclipse Sound and Pond's Inlet from the end of June to late in August, but they reach Home Bay and Cape Hooper about the middle of September. (Brown, 1875, pp. 79, 80.) They keep close to the ice and work southward to Cumberland Gulf, where

they remain until the accumulated ice drives them farther south. When bowheads were more numerous in the sixteenth and seventeenth centuries, they apparently followed the ice down to the Strait of Belle Isle and the St. Lawrence and remained there during the winter months. (True, 1904, pp. 12, 43.) In more recent years the southern limit of their winter range seems to have been approximately 58° north latitude off Labrador.

On the west coast of Greenland bowheads appear annually, with great regularity at definite seasons, and enter the larger sounds. The ice conditions there are different from those on the opposite side of the strait, and hence the seasonal occurrence of bowheads is somewhat different. According to the records of the old Danish fishery the bowheads on their southward migration make their appearance between Proven and Upernavik (72° and 73° N. lat.) late in September

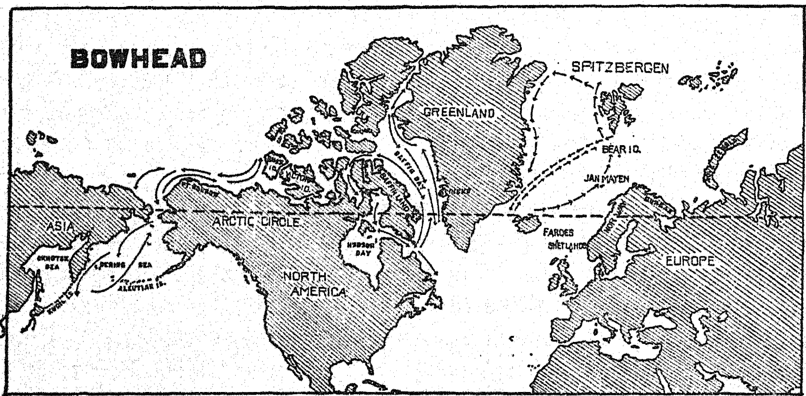


FIGURE 4.—Distribution map for the bowhead whale, with supposed migration routes in north latitudes. Adapted from Southwell (1898)

or early in October and remain until December, when they depart. They reach Disco Bay in December and some remain there until June, while others proceed southward to Holsteinsborg and Sukkertoppen. At Holsteinsborg the first bowheads appear during the last days of November or early in December, and occasionally a few remain as late as March. In severe winters bowheads were more numerous than normally in the larger sounds and fjords at Sukkertoppen during the months of December, January, and February.

It has been observed that the females and the young rarely migrate southward along the west side of Davis Strait in the autumn. The evidence assembled by Southwell (1898, pp. 409, 410) would seem to indicate that they follow a more westerly route than the males, and that they reach their winter feeding grounds through Hudson Strait. On August 15, 1829, Sir John Ross noticed many immature whales off Bellot's Strait at the upper end of the Gulf

of Boothia. Markham observed bowheads heading along the inlet into the Gulf of Boothia from which Fury-and-Hecla Strait would be the only southern exit. Richardson observed bowheads in Fox Channel near the shores of Melville Peninsula, in Frozen Strait, and in Hudson Strait. During Parry's stay off the coast of Melville Peninsula bowheads were observed from August 5 to 28, but none were observed going north earlier in the year. From these data it is obvious that females and immature whales have been observed migrating southward on an inside passage and that the sequence of dates for the several intervening localities fits in very well with the postulated route. It is also true that in former years bowheads were found in Hudson Bay, especially in the vicinity of Southampton Island and near Cape Fullerton (64° N. lat. and 86° W. long.) in considerable numbers from July 15 to August 1. (Clark, 1887, p. 18.) The Hudson's Bay Co. at one time operated a fishery on the coast of Eiwillick. It was the opinion of Dr. Robert Brown (1875, p. 81) that the western herds of bowheads were accustomed to pass the winter and bring forth their young in March and April in the broken water off Labrador and Hudson Strait.

I have been told by Mr. Charles D. Brower of Point Barrow, Alaska, that in the fall of the year the bowheads pass at that point on their southward run from September to November, depending upon ice conditions, and that on the Siberian side of Bering Sea they remain until November. Then the bowheads seem to journey westward toward Wrangell Island, off the Siberian coast. These bowheads spend the winter in drifting or field ice which joins the open water of the Pacific coasts about the Kuril and Aleutian Islands. They occur in the vicinity of St. Paul's Island, Bering Sea, in October. (Scammon, 1874, p. 68.) As the ice breaks in the spring of the year bowheads pass Cape Navarin (62° N. lat.) on the Kamchatkan coast in the latter part of March and Cape Hope on the Alaskan coast in April and May. Bolau (1895, p. 8) remarks that the North American whalers met with the first whales near the ice at about 60° north latitude and that they were accustomed to follow their prey near the shore along the retreating ice edge. Earlier in the season many bowheads were found near Karagin Island south of latitude 59° north on the coast of Kamchatka. The region between St. Lawrence Island and East Cape was likewise favorable for whaling. About the 1st of May bowheads were found in the Gulf of Anadir, and when the ice broke up in Bering Strait early in June they forced their way northward into Bering Sea. Brower's observations show that bowheads pass by Point Barrow, Alaska, from April to June, and that they proceed eastward to the mouth of the MacKenzie, to Bailey Island on Lady Franklin

Bay, and to Banks Land. They are known to be present off Point Franklin until as late as August 15. Bolau (1895, p. 8) is the authority for the statement that whalers sought bowheads as far north as 72° north latitude, where, according to Pechuel Lösche, they appeared to vanish beneath the ice. The young are born in May, for the most part north of Bering strait.

GRAY WHALE (RHACHIANECTES GLAUCUS)

The gray whale is found only in the North Pacific. This whale differs from other whalebone whales in that it has a habit of coming close inshore among the rocks and beds of kelp, and it has been ob-

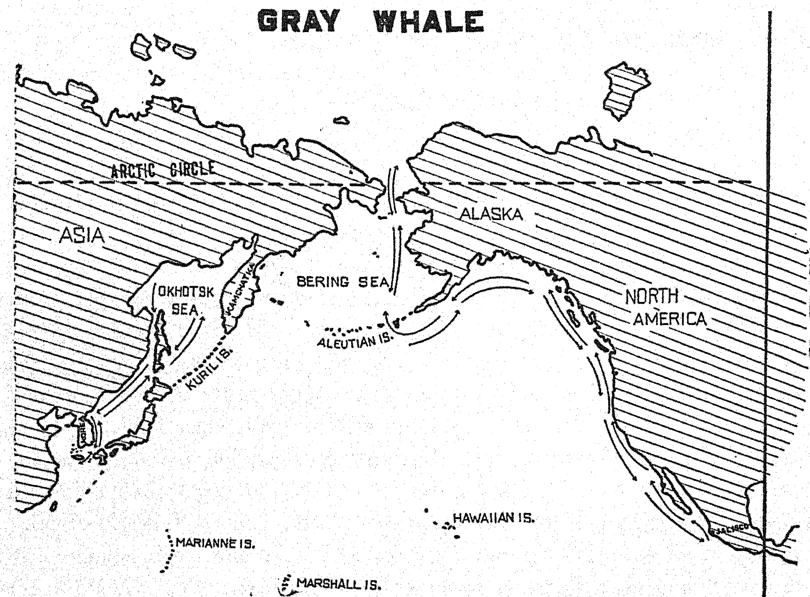


FIGURE 5.—Distribution map for the gray whale, with supposed migration routes in the North Pacific

served wallowing in surf which broke among the rocks. It makes regular migrations from hot latitudes to beyond the Arctic Circle.

Along the western coast of North America, according to Scammon (1874, p. 22), the gray whale does not migrate farther south than 20° north latitude, that is, about the latitude of the State of Jalisco in Mexico. The females enter the lagoons of the lower coast of Lower California and bring forth their young in the interval between December and March. By April the gray whales have passed Monterey on their northward run. On their northward journey they follow the coast, passing Vancouver and the Queen Charlotte Islands, and finally arrive in the ice-filled waters of the Arctic Ocean. During the summer months they congregate in the Bering Sea and

farther northward in the Arctic Ocean, where they force their way through the field of ice and scattered floes. In October and November they again appear off the coast of Oregon and California on their southward migration to their tropical winter haunts. In 1851, according to Scammon (1874, p. 23), it was estimated that 1,000 whales passed the shore stations of southern California daily between December 15 and February 1 on their downward run. To-day they are well-nigh exterminated along the North American coast.

Records obtained from the *Vega* whaling expedition operating at Magdalena Bay, Lower California, during the years 1924 to 1926 show that the gray whales do not arrive until about December 28. The southward migration reached its height about January 22 and ended about February 16. This expedition left Magdalena Bay on April 7 and did not meet with the northward migrating schools. The *Vega* expedition, however, resumed their operations at Nathalia Bay, Kamchatka, and from July 27 to August 22 noted gray whales in considerable numbers. (Risting, 1928, pp. 80–89.)

Toward the end of November, according to Andrews (1914, p. 235), gray whales appear at Ulsan, in southeastern Korea, on their southward migration. Pregnant females arrive first and they are followed by the males. By the end of January all the females have passed. The young are born in the bays among the numerous small islands at the extreme southern end of the Korean Peninsula.

On the northward migration they again appear at Ulsan (40 miles north of Fusan) in southeastern Korea, about the middle of March, and by the middle of May all have passed by. Gray whales are also found during this period at Broughton Bay on the coast of Korea, and they migrate past the east coast of Sakhalin Island. (Tago, 1922.) These herds pass the summer in the Okhotsk Sea.

BLUE WHALE (SIBBALDUS MUSCULUS)

Blue whales spend a large portion of each year in migration, but rarely gather in large schools. In the North Atlantic they move in early spring from the waters off the banks east of Newfoundland in a northeasterly direction to the Arctic Ocean, where according to Collett (1912, p. 586) they spend the summer. The return migration occurs in the autumn.

Blue whales seem to be partial to cold water and to avoid the tropics. In southern latitudes they approach the borders of the pack ice and traverse the cold northward-flowing currents. Off the North American coast they frequent the ice-chilled Nova Scotian current and the icy water that flows from the St. Lawrence as well as that which owes its origin to the Labrador current, but blue whales have been stranded as far south as Ocean City, N. J., and it is possible, as Allen (1916, p. 255) remarks, that they may follow

the cooler inshore waters as far south as the Carolina coast. Notwithstanding the fact that blue whales have commonly been held to be ice-loving animals, an exceptionally large individual entered the harbor at Cristobal, the northern entrance to the Panama Canal, in January, 1922. (Harmer, 1923, p. 1085.) The stranding of a large blue whale in December, 1916, on the south coast of the Preanger Regencies, Java, is recorded by Reuter (1919). An 84-foot whale which was washed ashore on Amherst Island, a small island south of Ramri Island, off Burma, during the last rains of 1851 may have been a blue whale, although it has been named *Balaenoptera indica.* These occurrences would seem to indicate that the tropical seas are traversed from time to time by blue whales, and that there may be an occasional intermingling of the northern and the southern herds.

Blue whales are rare visitants to the New England coastal waters, but as early as February they have been observed migrating eastward off the coast of Newfoundland, and in late March or April they pass Iceland. On March 1, 1903, Captain Nilson (Millais, 1906,

FIGURE 6.—Blue whale [*Sibbaldus musculus* (Linnaeus)]. Outline drawing. Notice the short fore flipper and the narrowly spaced throat grooves

p. 253) saw over 200 at intervals between Banquereau and St. Pierre Bank off Newfoundland. Blue whales are fairly common in March off Newfoundland and occur also in the Gulf of St. Lawrence after the ice goes out. From June to mid-August they follow the "kril," but a few return in late August, and small numbers stay until November. From March to November blue whales are found off the west coast of Greenland, generally south of the Arctic Circle.

In March and April at Faroe blue whales are observed coming from the southwest on their northward run. (Thompson, 1918, p. 234.) Other migrating blue whales pass the west coast of Ireland and the Hebrides in May and June. The records for the Scottish stations show that June to October is the main season for blue whales (Thompson, 1918, p. 232), but Haldane (1908, p. 69) remarks that they seem to be more common off Faroe, Iceland, and Finmark than they are off Scotland. The accumulated records indicate that blue whales are most abundant in the vicinity of the British whaling stations from June to September; for Iceland, June and July; and for Finmark, from June to August. (Harmer, 1927, p. 66.) Off Iceland at the beginning of the season in June blue whales are seen coming up

from the westward, and they move past toward the east. (Thompson, 1918, p. 233.) The records of the whaling stations show that the blue whales appear in the cold water off the Finmark coast from May to June. Varangerfjord was a favorite resort in the summer as late as 1880. Here blue whales rarely made their appearance as early as May, but generally about the middle of June, and they left by the middle of September. (Southwell, 1905, p. 414.) Thus during the summer months, June, July, and August, they are found in the Arctic Ocean and the North Sea off the coasts of Greenland, Iceland, Spitzbergen, Bear Island, and Finmark, and thence along the whole Murman coast to Nova Zemlya and the White Sea. Their departure from northern regions in the autumn seems to be correlated with the falling off of their food supply and not with a lowering of the surface temperature.

In autumn, particularly in August or early September, they migrate from the eastern Arctic Ocean toward the west and south in the open sea between Iceland and Faroe and at this season are found along the western coasts of the Hebrides and Ireland. In October and November migrating blue whales appear off the coast of Newfoundland. It is believed that they pass the winter in the open seas between the eastern coast of North America and the Azores.

Very little is known in regard to the migration of blue whales in the South Atlantic. They are known to occur in fairly large numbers in the open seas west of South Georgia during the month of December and are present in the vicinity of South Shetland in February and March. As early as December 30, 1892, blue whales were seen in the vicinity of Erebus and Terror Gulf, Graham Land. (Bruce, 1915, p. 494.) Blue whales were observed on December 31, 1909, in Bransfield Strait and they had advanced as far south as the Bay of Matha by January 14. (Liouville, 1913, pp. 4, 33–35.) On January 19, 1910, blue whales were noted as far south as 108° 17′ west longitude and 69° 15′ south latitude. Again on February 24, 1898, Racovitza (1903, p. 46) reported seeing a blue whale in the open sea at 81° 31′ west longitude and 69° 31′ south latitude.

No records for blue whales off the coast of equatorial Africa were found, but Mörch (1911, p. 664) states that they are found near the west coast of Africa in the summer.. Great numbers of blue whales have been observed off Saldanha Bay, Southwest Africa, in July, and a female with a newborn calf was taken on September 14, 1912 (Hinton, 1925, p. 192). The records of the whaling station at Saldanha Bay show that blue whales were taken from May 21 to October 10 in 1910.

At South Georgia some blue whales remain in the vicinity throughout the Antarctic winter. According to Risting (1928, pp. 21–22)

blue whales are more numerous than finbacks at the beginning of the whaling season in October. The arrival of blue whales seems to fluctuate from year to year, possibly owing to conditions prevailing along migration routes, for Risting found that the influx culminated in December in three of the years for which statistics were available, in January during another year, and in February during the fifth year. Again in 1925–26 large numbers of blue whales appeared in March.

Blue whales arrive before the finbacks at South Shetlands. In October and November off the South Shetlands the blue whales follow the retreating ice edge southward and enter Bransfield Strait as soon as conditions permit. Here the southward migration reaches its greatest maximum from December 20 to January 15, after which the blue whales force their way southward along Graham Land into waters with more abundant ice. With the approach of Antarctic winter, ice forms rapidly in the straits and sounds, and it is then that the whales retire from their feeding grounds and trek northward toward more temperate waters. (Risting, 1928, pp. 22–23).

The periodical appearance of blue whales on the west coast of Africa corresponds to the season when they are less numerous in the Antarctic. They appear off the southernmost point of Africa as early as April, where they are taken by whalers operating out of Saldanha Bay. Proceeding northward they pass Walfisch Bay sometime in May, and farther northward along the Angola coast they are most numerous in July, August, and September. On their southward run they again appear off Saldanha Bay in August, September, and October, although blue whales are taken at that station from April until December. (Risting, 1928, pp. 23–26.)

Captain Bryde observed what he thought was a blue whale south of Abrolhos Bank, north of Rio, Brazil, in about 22° south latitude (Hinton, 1925, p. 68), and they are reported to be present during the summer off the coast of Chile.

In referring to the rarity of records for blue whales in New Zealand waters, Oliver (1922, p. 562) remarks that they are exceedingly abundant in the Antarctic Ocean. Blue whales were observed on December 5 at 169° 18′ east longitude and 63° 3′ south latitude, and again on February 10 at 164° 38′ east longitude and 63° 22′ south latitude by Bull (1896, pp. 130, 202). This explorer (1896, p. 161) saw numerous blue whales south of the Antarctic Circle on January 13, 1895, in the vicinity of 177° east longitude and 68° south latitude. Wilson reported seeing many blue whales on March 4, 1904, off the Balleny Archipelago, 156° 20′ east longitude and 67° 30′ south latitude. (Liouville, 1913, p. 36.) The Terra Nova expedition also met with blue whales in the Ross Sea in January and February. (Lillie,

1915, p. 115.) On February 1, 1911, blue whales were sighted at 166° 17′ west longitude and 78° 38′ south latitude. In March they were seen near 67° south latitude and 161° east longitude. Thus it is evident that blue whales frequent the pack ice and the ice-chilled seas in the latitude of Victoria Land and Wilkes Land south of New Zealand during the Antarctic summer and that their northward migration, if such occurs, does not closely approach the New Zealand coastal waters. Waite has recorded occurrences of blue whales in Spencer Gulf and Corvisart Bay on the coast of South Australia.

The taking of blue whales in San Bartolome Bay and near Asuncion Island, Lower Calif., between latitudes 27° and 28° north are reported by Scammon (1874, p. 72). The same writer refers to the presence of large numbers of these whales off San Quentin and off Cedros Island, Lower Calif., in July. On July 17, 1928, several blue whales were sighted by W. L. Cruickshank, captain of the British tanker *Trinculo*, in the Pacific Ocean off Nicaragua at 11° 32′ north latitude and 91° 58′ west longitude. The records of the whaling stations on the Pacific coast indicate that blue whales occur at all seasons off the coast of California. From May to September blue whales are found close to the shore, where low surface temperatures result from the upwelling of cold bottom water with the prevailing offshore winds. In recent years blue whales have been infrequent visitants along the California coast, for not more than five were taken at Moss Landing from January 16, 1919, to May 3, 1922. An 80-foot blue whale was harpooned off southern California in the vicinity of San Clemente Island on July 15, 1927. They occur more frequently off Vancouver Island, for three were taken at Rose Harbor and seven at Haden Harbor in 1927. They first appear off Kyuquot, Vancouver, in March. (Andrews, 1916, p. 24.)

Blue whales are most abundant off the coasts of Japan during the winter and are infrequently killed during the summer. (Andrews, 1916, p. 327.)

FINBACK (BALAENOPTERA PHYSALUS)

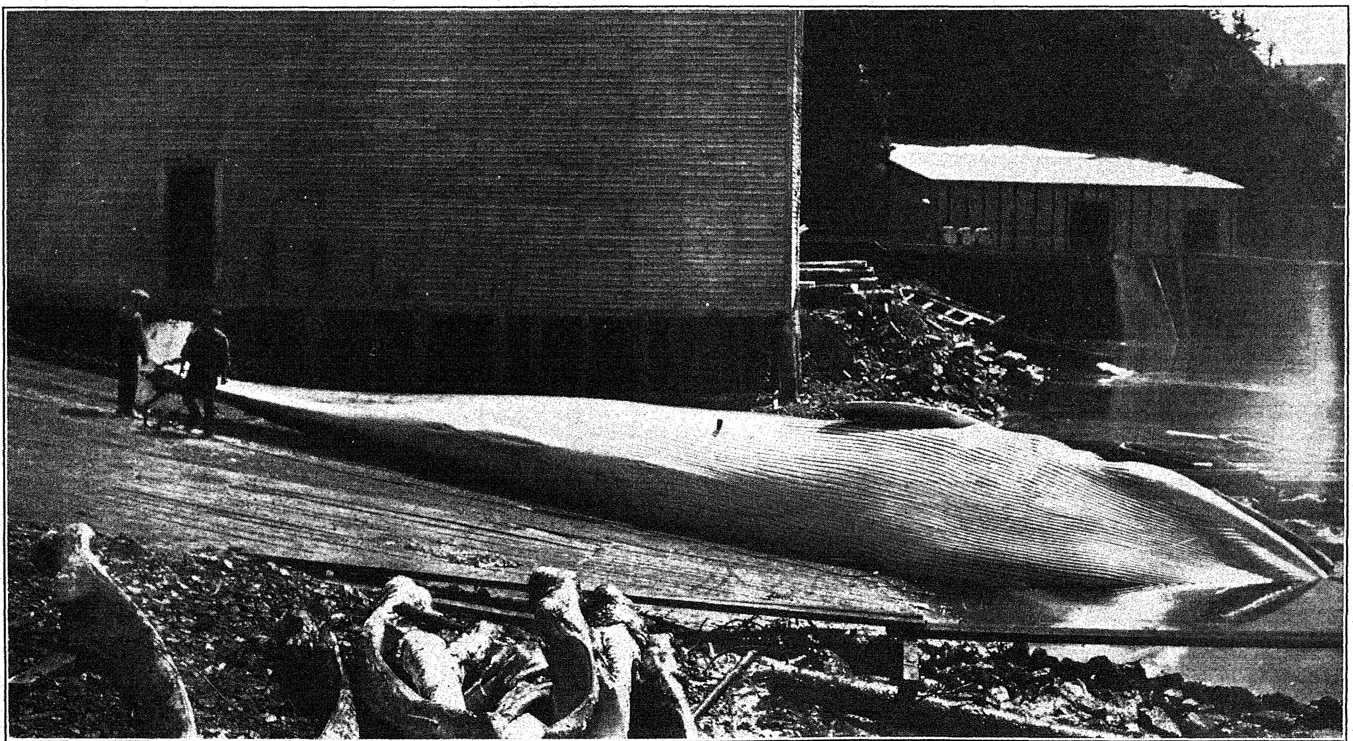
The migration routes of finbacks are not so well known as those of humpbacks, and the observed facts of gestation indicate that their journeys do not have any especial connection with their breeding habits. Their diet is subject to seasonal change and includes herring, capelan, and at times plankton. Climate seemingly has little influence in curtailing their wanderings, for finbacks appear to be indifferent alike to Tropic and Arctic temperatures, and travel where they will.

Finbacks are distributed over the North Atlantic according to season from Spitzbergen and Greenland southward to the Azores. Although they are much swifter swimmers than the humpbacks, they go to and from the same northern oceanic regions. On the

northward migration large numbers of finbacks have appeared in the Gulf of Maine early in March. (Clark, 1887, p. 230.) Other good-sized schools have been observed in May and June. Finbacks approach the south coast of Newfoundland as early as June. Off the northern coast of Newfoundland and Labrador they appear in mid-July and are most numerous in August. An unusual abundance of finbacks was noted on the Grand Banks near Newfoundland on July 13, 1885. (True, 1904, p. 65.) They are common summer visitors to Davis Strait and the cod banks off the west coast of Greenland. (Brown, 1875, p. 83.) Finbacks have been observed near Iceland as early as March, but most of them are taken along the Greenland ice in July and August. (Southwell, 1905, p. 408.) They become less numerous toward autumn. We are told by Hinton (1925, p. 128) that almost all of the whales passing the west coast of Ireland (Belmullet) in May appear to be moving in a northeasterly direction. From June to September finbacks follow the "Kril" off Rona's Voe and then disappear in a southwesterly direction. (Millais, 1906, p. 247.) Finbacks seem to occur at all seasons on the coast of Norway in mild winters, and strandings on the British coast have been reported from January to December. (Harmer, 1927, p. 64.) They follow the herring shoals in the winter along the west coast of Norway and the capelan in their visit to the Finmark coast in the spring. (Hinton, 1925, p. 127.) During the summer months large numbers of finbacks congregate in the vicinity of Spitzbergen and Bear Island. Pairing has been observed on the Murman coast during May and in the vicinity of Finmark from January to March. (Hinton, 1925, pp. 118, 119.)

Thousands of finbacks have been observed near the close of the whaling season between Iceland and Faroe according to Haldane (1907, p. 11). Toward September finbacks pass Ireland in a southwesterly direction and they have been observed heading south in the Bay of Biscay in October. They are also known to occur in the vicinity of the Azores and in the Mediterranean Sea. Southwell (1905, p. 411) is the authority for the statement that the finbacks leave the Newfoundland coast in October, and yet Millais (1906, p. 247) was informed by whalers that numbers of humpback, finback, and blue whales winter among the field ice on the Grand Banks off Newfoundland. It would seem that the summer feeding grounds of some of the finback and blue-whale herds may be occupied during the winter months by those that have spent the summer in the far north.

As regards the South Atlantic, Mörch (1911, p. 665) states that great numbers of finbacks congregate in the waters along the Brazil coast between south latitudes 12° and 18° every year during the period from May to November. They occur in the vicinity of South Georgia from November 15 to as late as the last week in May.



FEMALE FINBACK (BALAENOPTERA PHYSALUS (LINN.))

Taken by Cabot Steam Whaling Co. at Snooks Arm Station, Notre Dame Bay, Newfoundland, on August 10, 1899. Length, 50 feet 7 inches

Finbacks were observed by Mörch (1911, p. 667) off South Shetland in February and March. Risting's tables (1928, pp. 22–23) show that finbacks are taken off South Shetlands from November until May. The largest numbers are taken during January, February, and March. In 1921 the Norwegian companies alone took 862 in January, 964 in February, and 399 in March. The records show that 361 were taken in April, 1925. According to Liouville (1913, pp. 4, 44–45) finbacks were first seen on December 31, 1909, in Bransfield Strait, and on January 24 others were observed off the southern end of Adelaide Island. From January 16 to 18, 1909, finbacks were reported as far west as 108° 07′ west longitude and 69° 15′ south latitude. Great numbers of finners were seen on December 16, 1892, at 51° 01′ west longitude and 59° 24′ south latitude by Bruce, while on board the *Balaena* and during this vessel's stay in the vicinity of the Erebus and Terror Gulf, Graham Land, finners were seen from January 4 to February 7, 1893. (Bruce, 1893, pp. 493–494.) Numbers of finbacks have been reported to occur in the vicinity of South Georgia during the Antarctic winter, but numerically they are far below the normal summer abundance on these feeding grounds. These observations tend to substantiate migration at more or less regular intervals to other fields. (Risting, 1928, p. 20.)

For some inexplicable reason the finbacks appear to approach the western coast of South Africa from the north, and they are to be found moving southward off Saldanha Bay from March to June, although they are present in lesser numbers all the year round. (Hinton, 1925, p. 192.) As with the blue whales, finbacks are taken off Saldanha Bay on the west coast of Africa as early as April, but the whaling statistics indicate that they are most numerous in May, June, and July. Curiously enough the statistics for Walfisch Bay and for the Angola coast indicate that the bulk of the finbacks do not go as far north as the blue whales, for comparatively few individuals are taken at these stations. Judging from the catch during the seasons 1919 to 1925, finbacks are least abundant off Saldanha Bay in August and from then on increase in numbers until about the middle of November. (Risting, 1928, pp. 23–26.) On the east coast of Africa finbacks are said to be scarce, and yet in the years 1923 to 1927 more than one-fourth of all the whales caught off Natal were finbacks.

Finbacks are known to occur off the coasts of Peru and Ecuador, but there is little detailed information in regard to their seasonal abundance along the western coast of South America.

Oliver (1922, p. 562) states that finbacks are occasionally cast ashore on the New Zealand coast and mentions one stranded at Port Underwood on June 10, 1874. A list of the reported occurrences of whales, mostly unidentified as to species, for the Ross and Victoria quadrants of the Antarctic seas are tabulated by Racovitza (1903,

pp. 114–117), but no records for finbacks are included. Nevertheless, Bull (1896, p. 112) reports seeing many finners in the vicinity of the Royal Company Islands on October 20, 1894, and again at 164° 08′ east longitude and 64° 18′ south latitude on February 9, 1895 (p. 202). Then, too, Wilson on March 4, 1904, observed finbacks off the Balleny Archipelago, 156° 20′ east longitude and 67° 30′ south latitude. (Liouville, 1913, p. 36.) Lillie (1915, p. 116) reports that finbacks are very scarce in the Ross Sea and that "it is evidently not fond of ice-covered seas." He states that a finback was taken in October, 1912, off the Kermadec Islands.

In the North Pacific finbacks follow the coast on their northward run from Lower California to the Bering Sea. They appear off Kyuquot, Vancouver, as early as March. They have been taken in Frederick Sound off the southern end of Admiralty Island in August, and large numbers were observed off the south coast of Kadiak by True on September 3, 1895. Individuals are commonly taken off the California and Oregon coasts in May, June, July, and August. On the western side of the Pacific finbacks are taken off Aikawa, Japan, in May and June (Andrews, 1916, p. 320), but they are most abundant during the winter months.

SEI WHALE (BALAENOPTERA BOREALIS)

Sei whales have a roving disposition and occur sporadically in large numbers from time to time at widely separated localities. Great numbers were observed east of North Cape, Finmark, in 1885 and again in 1898. In the year 1885 they first appeared about the middle of May, but the bulk of them came early in July. At this time they were observed from the Tromsö coast to Varangerfjord, and also along the Murman coast. (Collett, 1886, p. 260.) The last of them were seen on September 8. A similar invasion (Haldane, 1907, p. 12) occurred in 1906 off the coast of Scotland and Shetland. Unusual numbers appeared in the vicinity of South Georgia in February, 1914 (Hinton, 1925, p. 173). Millais (1906, p. 277) was informed by Captain Nilsen that sei whales made their appearance in August and September on the south coast of Newfoundland and that large numbers were observed in Placentia Bay in August, 1903. Sei whales have been taken along the eastern coast of North America from Florida to Labrador, East Iceland, Europe, Africa, the Falklands, South Shetland Islands, Chili, Java, the Island of Solor in the Timor Archipelago, Japan, and on the west coast of North America.

In the North Atlantic, sei whales pass South Innishkea Islands, West Ireland, from the last half of May to the middle of June, and are also found along the coasts of Scotland and Shetland between the middle of June and the middle of July. In traveling northward

past the Shetlands, they are in the warm Gulf Stream which sweeps in past North Cape, Finmark, where they first meet the Arctic current. From here they spread out along the Finmark coast, though some also visit the Arctic Ocean between Spitzbergen and Nova Zemlya in the summer. There are stranding records for France, Holland, and Germany. Sei whales have been reported to occur as far south as Cape Blanco, Africa. (Andrews, 1916, p. 312.) This whale has been known to strand on the Florida coast in May and on the Virginia coast in March. There is an August record for Chatham Island, Mass.

Sei whales appear off Port Alexander, Benguela, about the middle of June and disappear in September and October. (Olsen, 1913, p. 1083.) Their visit to the Falkland Islands includes most of the months of February and March. Capt. H. G. Melson wrote Andrews (1916, p. 319) that he had passed thousands of sei whales between the Falklands and 20° south latitude off Cape Frio, Brazil.

Sei whales were reported to have been seen (Liouville, 1913, p. 110) off the Bay of Matha, in Bransfield Strait, and abreast the South Shetlands. Liouville also credits Amundsen with the discovery of this species in the Bay of Balæns close by the great barrier of the Ross Glacier and believes that the sei whale approaches closer to the South Pole than any other whale. There is a strong possibility that the piked whale may have been confused with this species.

Mörch (1911, p. 665) records the occurrence of sei whales off the coast of Chili. The Terra Nova Expedition met with sei whales during the month of October, 1910, along the northern limit of the drift ice south of Australia from 111° 18′ east longitude to 160° 3′ east longitude (Lillie, 1915, p. 117), but none was observed in the Antarctics. A young female was taken off the Bay of Islands, New Zealand, in the winter.

We have very little definite information in regard to their seasonal occurrence along the western coast of North America. Sei whales have been taken in the vicinity of Vancouver Island and one was taken at Moss Landing, Calif.

In the North Pacific it would seem that some of the sei whales pass the winter in the waters off the Indian Archipelago, for they occur in the vicinity of the Island of Solor in May. Leaving the southern islands of Japan, they work their way northward from April onward. June and July are the months when they occur in the greatest abundance along the eastern Japanese coast, but they rarely occur in the Japan Sea. (Andrews, 1916, p. 321.) In the North Pacific off Aikawa, Japan (approximately 40° north latitude), the sei whales came in early June and left before the 1st of September.

Since Aikawa, Japan, is fully 2,000 miles south of North Cape, Finmark, their northward migrations in the Pacific and Atlantic

Oceans may have some relation to favorable conditions for the propagation of plankton resulting from the flooding of warmer oceanic drifts with icy Arctic water. An Arctic current extends southward past Kamchatka, the Kuril Islands, and Hondo, the largest of the Japanese islands, to some distance south of Aikawa, while along the main islands of Japan south of Tokyo runs the warm "Kuro Shiro" or black current. (Andrews, 1916, p. 321.) The northward migrating sei whales meet the northern Arctic current at 40° north latitude off the Japan coast and at 70° north latitude off the Finmark coast.

Some of the sei whales which visit the northern coasts of Japan during the summer months spend the winter near Oshima and Nikishima in southern Japan in comparatively warm waters, while others proceed farther southward. One was stranded on the coast of Java in October.

The foregoing summary is rather brief and no attempt has been made to go into the subject in any great detail. It is believed that the available data indicates seasonal migrations and that the tabulation of the logs of whaling vessels would greatly increase our knowledge of the movements of these pelagic mammals.

LITERATURE CITED

Allen, Glover M., 1916. The Whalebone Whales of New England. Mem. Boston Soc. Nat. Hist., vol. 8, No. 2, pp. 107–322, figs. 12, pls. 8–16. September, 1916.

Andrews, Roy C., 1914. The California Gray Whale (*Rhachianectes glaucus* Cope). Mem. Amer. Mus. Nat. Hist., n. s., vol. 1, pt. 5, pp. 229–287, figs. 22, pls. 19–27.

Andrews, Roy C., 1916. Whale Hunting with Gun and Camera. D. Appleton & Co., New York–London, pp. XXII+333, with illus.

Andrews, Roy C., 1916. The Sei Whale (*Balænoptera borealis* Lesson). Mem. Amer. Mus. Nat. Hist., n. s., vol. 1, pt. 6, pp. 289–388, figs. 38, pls. 29–42.

Bigelow, Henry B., 1926. Plankton of the Offshore Waters of the Gulf of Maine. Bull. Bur. Fisheries, Washington, vol. 40, Doc. 968, pp. 1–509, figs 134.

Bigelow, Henry B., 1927. Physical Oceanography of the Gulf of Maine. Bull. Bur. Fisheries, Washington, vol. 40, Doc. 969, pp. 511–1027, figs. 207.

Bolau, Heinrich, 1895. Die Geographische Verbreitung der wichtigsten Wale des Stillen Ozeans. Abhandl. aus d. Gebiete der Naturwiss., Hamburg, vol. 13, pp. 1–22, with folding map.

Brown, Robert, 1875. On the History and Geographical Relations of the Cetacea Frequenting Davis Strait and Baffin Bay. In T. R. Jones [editor]. Manual of the Natural History, Geology, and Physics of Greenland and the Neighbouring Regions. London, pp. 69–93.

Bruce, W. S., 1915. Some Observations on Antarctic Cetacea. Report on the Scientific Results of the Voyage of S. Y. *Scotia*. Scottish National Antarctic Expedition, Edinburgh, vol. 4, Zoology, pp. 491–505, pls. 2.

Bull, H. J., 1896. The Cruise of the *Antarctic* to the South Polar Regions. Arnold: London, p. 243, with illus.

CLARK, A. HOWARD, 1887. The Whale Fishery. The Fisheries and Fishery Industries of the United States, sec. 5, History and Methods of the Fisheries, vol. 2, pp. 3–218, pls. 183–213.

COLLETT, ROBERT, 1877. Bemærkninger til Norges Pattedyrfauna. Nyt Magazin for Naturvidenskaberne, vol. 22, pp. 54–168.

COLLETT, ROBERT, 1886. On the External Characters of Rudolphi's Rorqual (*Balænoptera borealis*). Proc. Zool. Soc. London, No. 17, pp. 243–265, figs. A–G, pls. 25–26.

COLLETT, ROBERT, 1912. Norges Pattedyr, Kristiania, pp. x+744, with illus.

CORNWALL, IRA I., 1928. Collecting at Cachalot Whaling Station. Canadian Field Naturalist, vol. 42, No. 1, pp. 9–12. January, 1928.

ESCHRICHT, D. F., and J. REINHARDT, 1866. On the Greenland Right Whale (*Balæna mysticetus* Linn.) with Especial Reference to Its Geographical Distribution and Migrations in Times past and Present, and to Its External and Internal Characteristics. Ray Soc., London, for 1866, pp. 1–150, figs., pls. 6.

FLOWER, G. H. [editor], 1912. Science of the Sea. London: John Murray, pp. XVIII+452, with illus.

HALDANE, R. C., 1905. Notes on Whaling in Shetland, 1904. Annals Scottish Nat. Hist., Edinburgh, No. 54, pp. 65–72, fig. 1, pl. 1. April, 1905.

HALDANE, R. C., 1907. Whaling in Scotland. Annals Scottish Nat. Hist., Edinburgh, No. 61, pp. 10–15, pl. 1. January, 1907.

HALDANE, R. C., 1908. Whaling in Scotland for 1907. Annals Scottish Nat. Hist., Edinburgh, No. 66, pp. 65–72, April, 1908.

HARDY, A. C., 1928. Whaling Research. Nature, London, vol. 121, No. 3054, p. 771. May 12, 1928.

HARMER, S. F., 1923. Cervical Vertebræ of a Gigantic Blue Whale from Panama. Proc. Zool. Soc. London, pp. 1085–1089.

HARMER, S. F., 1927. Report on Cetacea Stranded on the British Coasts from 1913 to 1926. Publ. No. 10, British Museum (Natural History), pp. 91, text figs. 42, maps 7. February 26, 1927.

HINTON, MARTIN A. C., 1925. Reports Left by the Late Maj. G. E. H. Barrett-Hamilton Relating to the Whales of South Georgia. London, pp. 56–210, with 1 table.

JENKINS, J. T., 1921. A Textbook of Oceanography. London: Constable & Co., Ltd., pp. x+206, with illus.

KEMP, STANLEY, 1928. The *Discovery* Expedition. Nat. Hist. Mag., London, No. 6, pp. 183–197, figs. 2–9. April, 1928.

LILLIE, D. G., 1915. Cetacea. British Antarctic ("Terra Nova") Expedition, 1910. Natural History Report, Zoology, vol. 1, No. 3, pp. 85–124, pls. 8.

LILLJEBORG, W., 1866. Synopsis of the Cetaceous Mammalia of Scandinavia (Sweden and Norway). Ray Soc., London, for year 1866, pp. 219–309, figs.

LINDEMAN, MORITZ, 1880. Die Seefischereien, ihre Gebiete, Betrieb and Erträge in den Jahren, 1869–1878. Dr. A. Petermann's Mittheilungen aus Justus Perthes Geographischer Anstalt, Gotha, Ergänzungsheft Nr. 80, pp. VI+1–95, maps.

LIOUVILLE, J., 1913. Cétacés de l'Antarctique. Deuxième Expédition Anarctique Française (1908–1910). Paris, pp. VI+276, pls. 15.

MILLAIS, J. G., 1906. The Mammals of Great Britain and Ireland. London, vol. 3, pp. XII+384, illus.

Mörch, J. A., 1911. On the Natural History of Whalebone Whales. Proc. Zool. Soc. London, pp. 661–670, figs. 160–163.

Oliver, W. R. B., 1922. A Review of the Cetacea of the New Zealand Seas. Proc. Zool. Soc. London, pp. 557–585, pls. 4. September, 1922.

Olsen, Ørjan, 1913. On the External Characters and Biology of Bryde's Whale (*Balænoptera brydei*), a New Rorqual from the Coast of South Africa. Proc. Zool. Soc. London, pp. 1073–1090, pls. 109–113, December, 1913.

Racovitza, E. G., 1903, Cétacés. Resultats du Voyage du S. Y. *Belgica* en 1897–1898–1899, Anvers, Zoologie, pp. 142, pls. 4.

Reuter, W., 1919. An account of a Finback-Whale (*Balænoptera spec.*) which was Washed Ashore on the South-Coast of the Preanger Regencies in December 1916. Treubia, vol. 1, Livr. 3, pp. 1–1–38, pls. 1–20, December, 1919.

Risting, Sigurd, 1912. Knolhvalen. Norsk Fiskeritidende, Bergen, November, 11 Hefte, pp. 437–449, figs. 5.

Risting, Sigurd, 1928. Whales and Whale Foetuses. Statistics of Catch and Measurements Collected from the Norwegian Whalers' Association 1922–1925. Rapports et Procès-Verbaux des Réunions, Conseil Permanent International pour l'exploration de la Mer, Copenhagen, vol. 50, pp. 1–122. December, 1928.

Ross, James Clark, 1847. A Voyage of Discovery and Research in the Southern and Antarctic Regions During the Years 1839–43. Murray: London, vol. 1, pp. LII+366, illus.

Scammon, C. M., 1874. The Marine Mammals of the Northwestern Coast of North America, Described and Illustrated; Together with an Account of the American Whale Fishery. San Francisco and New York, pp. V+319, pls. 27.

Sars, G. O., 1875. Om "Blaahvalen" med Bemaerkninger om nogle andre ved Finmarkens Kyster forekommende Havdyr. Forh. Vid. Selsk. Christiania (1874), pp. 227–241.

Southwell, Thomas, 1898. The Migration of the Right Whale (*Balæna mysticetus*). Natural Science, vol. 12, No. 76, pp. 397–414, with 2 maps. June, 1898.

Southwell, Thomas, 1905. Some Results of the North-Atlantic Finwhale Fishery. Ann. & Mag. Nat. Hist. London (7), vol. 16, pp. 403–421. October, 1905.

Thompson, D'Arcy Wentworth, 1918. On Whales Landed at the Scottish Whaling Stations, Especially During the years 1908–1914. The Scottish Naturalist, Edinburgh, No. 81, pp. 197–208; No. 82, pp. 221–230; No. 82, pp. 230–237.

Townsend, Charles H., 1887. Present Condition of the California Gray Whale Fishery. Bull. U. S. Fish Comm., vol. 6, pp. 346–350, pls. 6–7.

True, Frederick W., 1904. The Whalebone Whales of the North Atlantic, Compared with Those Occurring in European Waters, with Some Observations on the Species of the North Pacific. Smithsonian Contr. Knowl., vol. 33, No. 1414, pp. 1–331, figs. 97, pls. 50. June, 1904.

ECOLOGY OF THE RED SQUIRREL[1]

By A. Brooker Klugh

Queen's University, Kingston, Ontario

[With five plates]

INTRODUCTION

The red squirrel (*Sciurus hudsonicus* and subspecies) is one of the commonest and most generally known mammals over a large part of North America. Under the name "*Adjidomo*" it has figured in Ojibwa and Cree myths and in Longfellow's "Hiawatha," and by the name of chickaree, common squirrel, barking squirrel, red squirrel, and l'ecureil rouge, it has been cited in early accounts of the country.

The present paper is the result of eight years' somewhat intensive study of this species in Ontario, Quebec, New Brunswick, and Prince Edward Island, covering the typical form (*hudsonicus*) and geographical races *loquax* and *gymnicus*, and an attempt is made to bring together the facts concerning the life-history, habits, food, relationships to other animals, economic importance, and psychology of this species which are to be found in the literature. Some details concerning the daily life of the red squirrel, and many points in connection with the psychology of this species which I have accumulated, are due to the fact that I had one individual under almost constant observation for months at a time for a period of two years and another for a year. These squirrels made their headquarters in a large sugar maple which stands in my garden, the lower branches of which are on a level with my upstairs balcony and the upper branches on a level with the window of my top flat. During these periods other red squirrels came into this tree more or less frequently, so that an opportunity was afforded to obtain data on the relations of one individual to others of its species.

---

[1] Contribution from the Zoological Laboratory, Cornell University. Reprinted by permission, with slight changes in the illustrations, from Journal of Mammalogy, vol. 8, No. 1, February, 1927.

ALBINISM AND MELANISM

Neither albinism nor melanism is common in this species. Bell (1898) says, "Melanism and albinism, or any variation whatever, is extremely rare. I obtained a specimen at Athabaska Lake which is pure white beneath, from nose to tail, the second half of which is also perfectly white." Adams (1873) writes: "On the reliable authority of Mr. Boardman I learn that there is a district on the south coast of the province [New Brunswick] where all the squirrels belonging to this species are black." Quoting a letter from Mr. Savage, Miller (1900) says, "Mr. John Bergtold of Browmansville, Erie County, N. Y., captured an adult and three young, all of which he kept alive. The adult and two of the young were perfect albinos; the other young was normal in color." Prof. J. N. Gowanloch, of Dalhousie University, informs me that he came across a case of partial, or "pie-bald," albinism in this species. Seton (1909) reports a pair of albinos on the authority of Paul Doherty.

HABITATS

The red squirrel is at home throughout its range wherever there are trees. The spruce forest, the pine forest, the maple-beech woods, and the mixed forests were its original habitats, but it now occurs in agricultural districts where the trees are reduced to farm wood lots, groves, orchards, and groups of shade trees, as well as in parks and in cities, towns, and villages where shade trees are numerous.

HOME RANGE

It is not an easy matter to determine the exact home range of any animal, but from my observations in the case of individuals which had some diagnostic characteristic I should say that the home range of the red squirrel is usually small, about two hundred and fifty yards square. Seton (1909) puts the home range of this species at less than ten acres, and says, "Many a one passes its whole life in an orchard of from four to five acres." Seton quotes Paul Doherty to the effect that a pair of albinos were always to be found within 80 feet of their nesting tree. Richardson (1829) would imply that the home range of this species is extremely restricted, as he says "It does not appear to quit the tree beneath which it burrows by choice, unless when it makes an excursion in spring in search of a mate." This is, however, certainly erroneous.

There is not any question but that, under unusual circumstances such as scarcity of food, the red squirrel makes excursions some distance outside what may normally be regarded as its home range.

That a restricted home range is decidedly advantageous is readily seen, as within this area the squirrel knows every tree and limb, every jump from one tree to another, and every hole, either in a tree or in the ground, so that its chances of escape when pursued by an enemy are much enhanced.

ABUNDANCE

The abundance of this species varies, not only from place to place, but apparently also from one season to another. In the original pine forests of Ontario, at the time the first cutting operations were going on, I should place the abundance of the red squirrel at not more than one to every 20 acres, and in the original maple-beech woods about the same. In the spruce woods of New Brunswick there are, as nearly as I can ascertain, about two squirrels to every hundred yards square. At Grand Bend, Ontario, on the shore of Lake Huron, in a piece of country with a mixed forest consisting of pine, hemlock, cedar, oak (red and white), beech, maple, butternut, and hickory, I found more red squirrels in the spring of 1923 than I have seen at any other place, and a census showed nine squirrels to the acre. Merriam (1884) says, "In seasons when mast is plentiful there seems to be a squirrel for every tree, bush, stump and log in the entire wilderness, besides a number left over to fill possible vacancies. When, on the other hand, the nut crop has been a failure, a corresponding diminution in the numbers of squirrels is observable, and they are sometimes actually scarce." The superabundance just quoted must certainly be a most unusual circumstance. The greatest local abundance which I have seen was 17 red squirrels in a group of 5 butternut trees in early September in a region in which these trees were scarce, and neither before nor since have I seen anything like such numbers gathered together.

Dice and Sherman (1922) report the numbers found in different habitats in Michigan as follows: black ash swamp, 1; cedar swamp, 3; black spruce-tamarack bog, 2; hemlock forest, 1; white pine forest, 1; wet hardwood forest, 9; dry hardwood forest, 7; shrub stage of hardwood forest, 1; paper birch-aspen woods, 3; early hardwood stage of forest, 1.

MIGRATION

The red squirrel is certainly nonmigratory except under very unusual circumstances. Such circumstances seem to prevail in the Adirondacks as Merriam (1884) says: "James Higby tells me that in June, 1877, he saw as many as 50 crossing Big Moose Lake, and that they were all headed the same way—to the north. I am informed by Dr. A. K. Fisher that at the southern end of Lake George, in early autumn, it is sometimes an every day occurrence to see red squirrels swimming across the lake, from west to east—never in the

opposite direction. The chestnut grows abundantly on the eastern side of the lake, but is comparatively scarce on the western, and these extensive migrations always take place in years when the yield of chestnuts is large;" and again, quoting Winslow C. Watson, "The autumn of 1851 afforded one of these periodical invasions of Essex county."

MATING

In Ontario red squirrels mate in March and at this time there is more chasing about among the branches than at any other time. Seton (1909) says that in Manitoba they mate late in March or early in April. Nelson (1918) notes that the males fight in the spring and sometimes inflict serious injuries on one another.

Whether they pair for life or even for a single season is a doubtful point. Seton has seen two adults at work building a nest, and notes that the two albino squirrels mentioned above were seen together all summer and winter. Certainly neither the male which I had under observation for two years, nor the female which I observed for over a year, had a mate associated with it, though the latter brought one young to the tree with her during late June and early July.

NESTING

The nests of the red squirrel are of two kinds: nests made in holes in trees or stubs, and the large outside nests made of leaves and other materials. Both kinds serve as winter homes, but the young are usually born in a cavity in a tree, frequently in one excavated by the flicker.

In the far north where the timber is small the outside nests are used almost exclusively. Osgood (1900) says of the red squirrel of the Yukon, "Its globular nests of grass, moss, bark and refuse are common and are usually found situated near the trunk of some slender spruce, 10 or 20 feet from the ground. Sometimes several will be found in the same tree, and half a dozen or more are very often to be seen at the same time."

Cram (1901) says of these outside nests:

> When convenient, he chooses the nest of some large bird for a foundation, and in this builds a structure of moss, bark, pine-needles, and dead leaves, with walls several inches in thickness, and a soft nest of dry grass and feathers inside. The bark used is of two sorts, the rough outer bark of different trees, broken into small pieces, and what appears to be the inner bark of the red cedar, torn into narrow strips, or ribbons to bind the whole together. The narrow opening at one side is provided with a hanging curtain of moss or some similar substance, easily pushed aside by the inmates, but immediately falling back into place and effectually concealing the entrance. If unable to find a bird's nest situated to their taste, the squirrels arrange a loose platform or framework of twigs in a convenient crotch and build their nest on that.

Some of the nests which I have examined in Ontario and New Brunswick were very compactly and firmly built, while others were somewhat loosely put together.

YOUNG

In Ontario, New Brunswick, and Manitoba, the young are usually born early in May, but many broods are considerably later. I have on several occasions seen young squirrels but little more than half-grown in September and October, and at Lake Missanag on September 6 I saw an adult and five half-grown young on the trunk of a large dead hemlock, in which, at a height of about 25 feet, was their nesting-hole. These late occurrences of young may possibly indicate a second brood, though, if this is the case, it is certainly the exception and not the rule.

Speaking of *S. hudsonicus richardsoni*, Bailey (1918) says:

> In June the four to six young are born in the big grass nests up among the branches of the trees or in well-lined hollow trunks. For a long time they are naked and helpless, and apparently they do not usually come out of the nests as half-grown squirrels until the latter part of July. They are carefully watched and nursed and fed by the mother squirrel until they have learned the ways of the woods, and by the latter part of August have scattered out, each storing his own winter supplies or all working and storing together as a family for the winter's supply about the old parental tree. Usually the families do not entirely break up until the following spring.

Seton (1909) says:

> A home nest which I had found at Carberry, Manitoba, June 24, 1882, was 20 feet up in an abandoned Flicker's hole in a poplar stub. It contained five young. They were blind, naked and helpless, and had no sign of aural orifice. They measured about 4½ inches long, including the tail, which was 1½ inches. While I was up the stub the mother dashed up and down the far side, running over my hands and arms, in her distress for their safety, quite reckless for herself. I put the young back, intending to come again and watch their development. But the mother had other plans for them. She removed them at once, and I did not discover their new abode.

And, again, speaking of a female which raised her brood for several years in a box set in a thin hemlock near his house, "In June I often see the little ones following the old one in a sort of procession through the trees. This is no doubt their training."

Cram (1901) thus describes the young:

> The young squirrels are most absurd looking little beasts at first, like miniature pug dogs, blind and naked, and with enormous heads. In a few days their fur begins to show like the down on a peach, and as a fringe of short hair along each side of the tail, which at length assumes something of the flattened aspect of that worn by their elders, but without displaying much of the fluffy, shadowy quality of the ideal squirrel tail until late in the following autumn. Although they do not remain long in the nest, they are seldom seen abroad until fully grown, or very nearly so, which is rather remarkable when you come to consider the number that are brought up each summer in

every pine grove or thicket where these squirrels are abundant. Occasionally you may see a family of them playing timidly about among the branches, but without displaying any of the self-confident recklessness of their elders, quick to take alarm at the slightest hint of danger and scurry back into concealment.

I have seen two squirrels about two-thirds grown following an adult in early October in Ontario, but they had passed the stage of timidity mentioned above; plate 2, figure 2 is a photograph of one of them, which shows curiosity personified. In July in New Brunswick I have seen an adult and four young feeding together in the tamaracks.

LENGTH OF LIFE

There are, as far as I know, no data on the length of life of the red squirrel in the wild condition, but Charles Macnamara informs me that one which he caught when a few months old, and had in captivity, lived for nine years. The account of this squirrel, as given by Mr. Macnamara follows:

When I was a young fellow, while walking along a woodland path with some friends one day about the middle of May, we noticed a small red squirrel with a rather large head, playing on an upturned root. As we came closer to look at him, he sprang to the ground and, apparently taking me for part of the scenery, ran up my leg and under my coat to my shoulder. When I caught him in my hands he did not seem much afraid and made no attempt to bite; and I carried him home wrapped up in a handkerchief in my pocket.

When the squirrel was offered food, it was seen that he was too young for anything but milk, and so he was fed for some weeks—I do not now remember just how long—by dipping a shred of sponge into milk and giving it to him to suck. Presently he began to lap from a saucer and to eat a little milk-soaked bread. Next he began to nibble at nut kernels, and finally toward the end of the summer he could gnaw open walnuts and filberts for himself. This all happened some 25 years ago and I can not recall exact dates, but my recollection is that at what I judge to be four or five, perhaps six, months of age, he was eating adult squirrel food.

For about a year he was quite tame and harmless, and was permitted to run about the house a good deal. But he began to bite people occasionally without the slightest provocation—just for the fun of the thing; and loving to explore cupboards and drawers, if the opening was not wide enough to let him in, he would try to enlarge it with his teeth. One day he was caught eating his way into an expensive bureau, and an incensed household demanded his confinement.

The tea chest that had heretofore been his home was replaced with a box three feet long by two feet deep and high, with a wire-netting front and netted windows at either end. A little box, eight inches by four inches by four inches with a small arched door in the end, nailed in one of the upper corners served as a sleeping place. This cage was kept on a verandah all summer, and was moved into a hallway in winter. He was a very cleanly little creature, and I never noticed the slightest smell from him. He always frequented one particular corner of his cage in answer to nature's calls, and, by my putting a little dry earth there, renewed every few days and keeping the floor covered with fresh sawdust, his cage was always fresh and clean.

These were narrow enough quarters for such an active animal as a squirrel, but a system of exercise he invented kept him in good condition during what was probably a long life for a squirrel. A " daily dozen " was not nearly enough for him; he took a daily thousand. Dashing across the floor of his cage, he flew up the wire netting front, and flung himself, back downward, across the ceiling, and then down the back of the cage and across the floor and up the netting again, going round and round so rapidly that he appeared not more than a streak. He would keep this up for 5 or 10 minutes at frequent intervals all day, and his steady thump, thump, thump, became a familiar sound around our house. He had a habit of bringing out a large mass of the cotton-waste of his bed and carrying it in his mouth while he was going through these gyrations.

He seemed to know me better than anyone else, and I grew very fond of him. One day, coming home at dark from an outing, I was told the sad news that he was missing. Somehow he had scratched open the back door of his box, and he had last been seen dashing through the raspberry bushes in the garden, with our big tom cat close behind him.

I went to bed with a heavy heart and got up before sunrise to look for his remains. It did not seem possible that he could have escaped, and I did not expect to find more than his tail. The dew on the shrubs in the garden soaked me, but I found no trace of the squirrel. I wandered disconsolately out of the garden and across the yard, and was standing aimlessly in an open shed when I heard a slight noise overhead. There was my squirrel on a beam above me, and when I held up my hand to him, he came down a post with the usual red squirrel hesitations, and leaped onto my arm. The call of the wild was not for him. He preferred his safe comfortable cage where there were plenty of Grenoble walnuts and no fierce cats.

One winter all the hair came off his back from neck to tail, exposing his livid blue skin. I rubbed a little vaseline on him, but hesitated to apply any remedy, as like all animals, and some primitive peoples, his sole idea of therapeutics was to lick the place, and I was afraid of poisoning him. But after some months the hair grew in again as thick and healthy as ever. His usually excellent coat was a little darker than that of the average wild squirrel. He was fed principally on filberts, almonds and walnuts, and his pampered appetite showed little interest in the local hickory and beech nuts or acorns. The only wild food he really seemed to like was pine cones. He got quite excited when he caught sight of them and seemed greatly to enjoy tearing them to pieces.

The ancestral habit of his race to lay in a stock of food for the winter was very strong in him. Although he was never hungry for five minutes in his life, he acted as if a dire famine was threatening. The nuts given him every day were always rather more than he needed, and he carefully stored the surplus in his sleeping compartment, gradually accumulating such a hoard that there was scarcely room enough left for him to get in himself, and he had to sleep with his tail hanging out. I used then to shut him out of the compartment and remove the nuts by a back door. This always caused a great fuss. He was being robbed of his hard-won store, and he would surely starve to death next winter! He chattered and scolded, and scratched frantically at the slide that shut him out of his bedroom, and dashed around the cage in great excitement. He did not quiet down until he was let into the compartment again and given a few nuts to start a new hoard.

He never made any determined attempt to gnaw his way out of the cage—which was made of half inch ash, and would not have been hard to eat

through—except in his sleeping chamber, where I eventually had to fit a piece of tin to stop him. His idea was probably to enlarge the chamber and not to escape. His teeth were always in good condition, but his claws used to grow long and curved inwards, so that I had to cut them every few months.

Up to his fifth or sixth year his activity was as great as ever. Then he began to show signs of age. In his youth he used to leap straight into the door of his bedroom; later I set a branch diagonally from a lower corner of the cage up to the door, and for a long time he could climb this nimbly enough. As his infirmities increased he gave up his circling exercise and at last I had to replace the branch with a flat board with grooves cut across it, up which he used to hobble to bed.

The direct cause of his death I think was lead poisoning contracted from some freshly painted furniture which was placed near his cage to dry. He may have reached out and licked the paint, or perhaps the fumes were enough to kill him in his decrepitude. As well as I can remember, he was in his ninth year when he died.

PERIODS OF ACTIVITY

The red squirrel in Ontario is active at all seasons, except for periods of a day or two at a time in extremely stormy, cold weather in the winter. Merriam says of it in the Adirondacks: "He remains active throughout the continuance of excessive cold. When fierce storms sweep over the land he retires to his nest, to appear again with the first lull of the wind, be the temperature never so low." Dice (1921), however, reports that in Alaska "When the temperature drops below −30° F. very few squirrels are active and they become dormant at lower temperatures."

The red squirrel's daily period of activity in summer is usually from sunrise until twilight. I have found that very few are about earlier than sunrise, and I have never seen one abroad after dark. Others, however, report that these squirrels are sometimes active at night. Merriam (1884) says "He may sometimes be discovered in the darkest hours of the night, stealing softly over the ground—bent, doubtless, on some errand of dubious propriety. Moonlight evenings he is often active, though not so noisy as during the day, and in early autumn vies with the flying squirrel in nocturnal nut-husking exploits." Nelson (1918) states that it "sometimes continues its activities during moonlight nights, especially when nuts are ripe and it is time to gather winter stores." Judging by the two squirrels I have had under constant observation, this species is not an early riser in the winter, as neither of them put in an appearance at their tree, around which much food was stored, until well after daylight.

RESTING

The red squirrel is usually spoken of as being "constantly active," but this is not absolutely correct, as both individuals which I have observed closely rested for a time each day in spring, summer, and autumn, the period of rest, and sometimes of sleep, being usually

between 1.30 and 3 o'clock. I have seen other squirrels in various parts of the country thus resting in the early afternoon, and the squirrel's reputation for "constant activity" is probably based on the fact that they are readily seen when they are active, and have not been noticed when they are not.

The resting attitudes are various, but there are two chief ones. In one of these the animal spreads itself out on a limb, with the tail lying out behind (Pl. 3, Fig. 1) and the chin resting on the limb; in the other, the squirrel squats down, rests the chin on the limb and folds the tail close over its back (Pl. 3, Fig. 2). Variants of these positions are that the tail may be folded down over the back in the first position and that it may be stretched out behind, or hanging to one side, in the second. A less usual resting position, the animal fitted into a fork with the front of the head resting on the limb, is shown in plate 3, figure 3. Sometimes, but as far as I have observed very rarely, the squirrel may go sound asleep in any of these positions. As a rule it closes its eyes only for a few minutes at a time, but on the other hand it may remain for half an hour or more without opening the eyes widely.

After resting, the squirrel almost invariably stretches, first one hind leg and then the other, and yawns widely, curling the tongue upward like a dog.

SUNNING

In the winter and early spring the red squirrel often selects a more or less sheltered spot and basks in the sun, sometimes for an hour or more at a stretch.

ACTIVITY IN THE TREES

The agility of the red squirrel on the trunk, limbs, and the finest twigs of the trees is remarkable. Sometimes it bounces about among the branches like an animated rubber ball, moving at such a rate that it becomes a mere blur. It travels about in the trees at such a speed, in such an apparently reckless manner, and in places where its hold seems so precarious, that the wonder is not that it falls occasionally, as it does, but that it does not fall a dozen times a day. I have seen a squirrel sitting apparently entirely unconcerned on one of the topmost twigs of a 70-foot elm, when a stiff wind was swaying the upper branches through an arc of about four feet, eating an elm bud held up in its forepaws. It travels with ease on the underside of limbs, both large and small.

LEAPING

The red squirrel makes long leaps from tree to tree, but these are always made when the landing place is lower than the point from which it takes off. A jump which one of the squirrels I had under constant observation made many times a day was a distance of 8 feet with a drop of 2 feet, and I noticed that it never tried the return leap. The most remarkable leap I have seen a squirrel make was a distance of 5 feet with a rise of 3 feet. Seton says that after measuring many bounds recorded in the snow, and made by squirrels pursued by dogs or hunters, he does not think that they can leap more than five feet on the level. In these cases the soft snow probably impairs the efficiency of their "take-off."

In leaping, the squirrel extends its legs and flattens its body, while the tail is straight and stiff behind it. In most cases the leap is very cleanly made, but sometimes, in cases where the object from which it has jumped is insecure or springy, or when the squirrel leaps with a bulky load, its leap is not so well controlled, and it makes desperate efforts by movements of the tail and legs to maintain its direction while in the air. In such cases it often makes anything but a graceful landing.

FALLING

The red squirrel very rarely falls, but occasionally does so. I have never actually seen one fall, though I have witnessed their having very narrow escapes from accidents upon many occasions. I once came across a young squirrel, which had apparently fallen from a high limb of an elm onto a cement sidewalk. It was squatting on the walk, looking very dazed, and rubbed its head with its fore paws repeatedly. Mrs. Klugh has seen a squirrel fall from a branch of the tree in our garden on two occasions. In both cases the squirrel was an intruder and was being vigorously pursued by the squirrel which "owned" the tree. In neither case did the squirrel alight on its feet, but in one case came down so heavily on its side as to apparently "knock the wind out of it" and it was some minutes before it recovered sufficiently to crawl to the tree and climb up; and in the other case the squirrel fell on its back on a sheet of ice and appeared to be badly shaken. The fall in each of these cases was a distance of about 30 feet.

Gosse (1840) describes how a squirrel in a grove of tall slender trees was chased from tree to tree for half an hour by shaking the trees violently. "He several times missed his hold, but always caught a bough in his fall, except once, when he came rather heavily to the ground from one of the topmost branches; he was instantly on his feet again and up in a tree before I could come near him."

Cram (1901) says:

On still winter days you may see them springing about among the elastic branches (of the hemlock), clinging to the very tips of the finely divided sprays at a perilous height in their endeavors to reach the cones that are hung on such exasperatingly slender twigs, hardly large enough even for a squirrel's foot to grasp; and not infrequently a misstep will send one of them headlong down toward the earth, usually to save himself by catching hold of one branch or another on the way down. If there should chance to be no branches beneath him, he spreads himself out, like a flying squirrel, to a remarkable degree of flatness and strikes so lighly as to escape all injury, even on hard snow crust or ice.

That the tail acts not only as a rudder in leaping, but to a certain extent as a parachute in the case of a fall, is probably true. Seton (1909) says that the loss of the tail "is a serious handicap, as is proved by the fact that a tailless squirrel rarely survives. The loss seems to limit its jumping power, and when it falls it suffers a heavy jar, from which the tail would have saved it"; and speaking of a squirrel which had its tail stripped off by a trout: "The animal was not obviously crippled, and yet, as usual, the tailless one disappeared." He also mentions a red squirrel which was found dead under a tree by Francis Dickie in Manitoba. "The tail was gone, except half an inch of stub, which looked as if it had been chewed off."

ACTIVITY ON THE GROUND

Though decidedly an arboreal species the red squirrel is quite at home on the ground. Except under very unusual circumstances it rarely gets very far out into the open, and its usual route in traveling over the ground is from near the base of one tree to the proximity of the base of another, the intervening space, if of any considerable extent, usually being covered in a succession of long, rapid bounds. Its activities on the ground are usually connected with food or drink, or to get from one group of trees to another. Some of its storehouses are holes in the ground, usually beneath a tree or stump, and it buries nuts here and there in the soil.

TUNNELLING IN SNOW

In winter the red squirrel makes extensive tunnels under the snow. These tunnels are made sometimes to connect one storehouse with another, sometimes to get at food material which is lying on the ground. One year, when my sugar maple had produced a very large crop of keys, the squirrel constructed a system of interconnecting tunnels with several entrances and exits to reach his food supply. Cram (1901) says, "Often, instead of burrowing down repeatedly to each little pile of cones, they dig radiating tunnels along the surface of the ground, from the first one opened to the others near it, drag-

ging the cones laboriously along their winding galleries to the surface and away over the snow to some favorite stump before attempting to open them." In digging these tunnels the squirrel does not bring any snow to the surface, but packs it against the walls, and makes a shaft to the surface either at the end of a tunnel or where two tunnels connect.

SWIMMING

That red squirrels swim well has already been shown in the section on migration, as Big Moose Lake, which they are reported as swimming across, is about a mile and half wide, and Lake George, at the point they crossed, about two miles wide. Cole (1922) saw a red squirrel swim to shore after having crossed White Sand Lake, Wis., and was told by a boatman that they had been doing this for some days past. "The individual we saw swam calmly and evenly with the head well up, shoulders nearly submerged, but rump and tail high. It did not seem at all fatigued when it reached the land."

A very peculiar incident is thus described, in a letter to me, by Allan Brooks:

> I was walking along a big mining ditch about 9 feet wide in which the water was running swiftly when I saw a curious animal coming down the bank on the other side. Presently I saw it was a red squirel staggering under the load of a two-thirds grown young one wrapped round its neck just back of the head. It came straight for the water and swam across, landing in front of me, and climbed the bank to my feet. Here it first caught sight of me, threw off the young one, jumped into the water, swam over, ran up the bank and into the woods. The young one ran up me, stopped on my chest just below my chin for a second or two, then ran down into the water, swam across, ran up the bank and off into the woods after its mother.

MANUAL DEXTERITY

Though the squirrel lacks a "thumb" its dexterity with its fore paws is much greater than in the case of most mammals. By taking them between its paws, it handles both large and small objects with precision and certainty. It can turn a smooth and slippery nut round and round in its paws, and only very rarely does it let anything drop.

I have on three occasions seen a squirrel reach out and pull off a bud with a single paw, in doing so folding the toes against the palm. I have also seen a squirrel pick rose hips with one paw and convey them to its mouth.

BALANCING OF OBJECTS

The red squirrel is an expert in balancing objects on branches. Usually it selects either a crotch, or the somewhat flat surface at the point at which a horizontal branch comes off from a limb, as the place of deposition. When placing anything in position it shifts it a trifle to one side or the other with its paws or its muzzle, and does not leave the object until it is as securely lodged as possible. I noticed that when one of the squirrels I had under observation hung a long strip of ham rind (an article of diet with which it could hardly have had previous experience) on a branch, it shifted it until the two ends hung equally on each side of the branch.

PLAY

Adult squirrels frequently play together, their recreation taking the form of a game of "tag" in which the utmost vivacity and agility is displayed. A good deal of what is commonly reported as a game of tag is, however, really not play but the chasing of one squirrel by another when the former has been poaching on its preserves, and it is only when the same squirrel is alternately pursuer and pursued that one can be sure that it is really a game.

The squirrel which I had under observation for 2 years, and which was at least 3 years old toward the end of the period of observation, frequently indulged in play by itself. When the first snowfall came it plunged about in the snow, dashed through the deep piles on the large limbs, and quite evidently enjoyed itself thoroughly. It frequently went through a remarkable performance which one must classify as a game since it certainly served no useful purpose. At the top of the trunk of the maple, at the point at which the main limbs are given off, there is a trough-shaped, vertical cavity some eighteen inches long with a pocket-shaped bottom. The squirrel often got in this cavity, turned over and over in a series of somersaults, sliding down the trough on its back at each backward turn. It sometimes also seized and held onto its tail and rolled about in the pocket.

DIET

The diet of the red squirrel is extremely varied, and naturally differs considerably in various parts of the country. One reason for the wide range and abundance of this species, and for its ability to inhabit a region under the changed conditions produced by civilization, is unquestionably its omnivorous propensity.

The two staple articles of diet of the red squirrel, taking the whole of its range into consideration, are undoubtedly the seeds of coniferous trees, and nuts. By far the greater part of the red squirrel's range lies in the Canadian and Hudsonian zones, which are vast areas of spruce and fir forests, and there are unquestionably more squirrels which feed most extensively and for a longer period each year on the seeds of these conifers than upon any other kind of food. In the typically Canadian zone country in New Brunswick this species feeds very largely on the seeds of white spruce (*Picea canadensis*) and red spruce (*P. rubra*) from the middle of August until May, and some idea of the immense quantities consumed may be obtained from the huge piles of scales to be found in the spruce forest and the large areas which are covered with these scales. Osgood (1900) speaking of Alaska, says, "The ground is often strewn for some distance with the scales of spruce cones which they have stripped. Near Lake Marsh I found one such place 20 feet square which was covered 6 inches deep with scales." Bell (1898) says, "The seeds of the black and white spruce constitute their grand staple in the North." The seeds of practically all the other conifers, in their respective regions, furnish the red squirrel with a large part of its sustenance. The seeds of the cedar (*Thuja occidentalis*) are eaten extensively in New Brunswick, Quebec, and Ontario, and the seeds of the hemlock (*Tsuga canadensis*), which remain in the cones on the trees all winter, are eaten throughout the winter in northeastern North America. Seton (1909) states that "In the country about Kenora (northern Ontario) the principal autumn (and therefore winter and spring) food of the squirrel is the seeds of the jack pine." The seeds of the white pine (*Pinus strobus*) are consumed extensively throughout the range of this tree, and Cram (1901) says, "The white pine is usually rather sparing in its yield; but once in every 10 or 15 years, perhaps oftener, nearly every tree in the forest bears enormously, even the younger ones showing scattered clusters here and there, while those that have stood for generations present a roughened, shaggy aspect from the thickly crowded cones at their summits. At such times the red squirrels seem determined to gather every cone before it opens and scatters its seeds to the winds." Bailey (1918) mentions the lodgepole pine, Douglas spruce, Engelmann spruce, mountain white pine, white-barked pine, western tamarack, and western balsam as furnishing the chief food supply of *S. hudsonicus richardsoni* in the mountains of northwestern Montana.

Farther south all kinds of nuts, within their respective ranges, constitute the main food of the red squirrel, since they are not only eaten at the time of their ripening, but are hoarded for consumption during the winter and spring. But nuts never bulk as largely in the menu of the southern squirrels as do the seeds of conifers in the

diet of those of the North, because, firstly, there are few, if any, localities where nut-bearing trees occur in which some species of conifer does not occur and furnish part of the squirrels' food, and, secondly, nowhere do nut-bearing trees form the dense, pure stands that the spruce does in the north. Beechnuts, hickory nuts, black walnuts, butternuts, chestnuts, and hazel nuts are all eaten both fresh and stored wherever they occur. Bell (1898) says, "Northward of the zone of butternuts, and beechnuts, etc., the hazel extends a long way—say, to a line drawn from Lake St. John (on the Saguenay) to Lake Athabaska, curving southward of James and Hudson Bays—and affords a large proportion of their food."

In the mixed forests of the Alleghanian faunal area the acorns of the white, red, and burr oaks, and the keys of the sugar maple and soft maple constitute a very considerable proportion of the food of this species.

In the spring the red squirrel eats the buds of a large number of trees, both when they are swelling and when they are partially expanded. It is probable that it takes the buds of any deciduous tree, and of some conifers, such as the spruce, but the buds which I have actually seen it eat are those of the sugar maple, soft maple, elm, beech, ironwood, yellow birch, hybrid willow (*Salix alba* x *fragilis*), poplar (*P. tremuloides*), and spruce, and the staminate catkins of the tamarack and red oak. When feeding on buds of the sugar maple and elm, and on the staminate strobili of the tamarack, I have on several occasions seen squirrels hang down by their hind feet from a twig to reach buds on the tips of the twigs beneath them, usually pulling themselves up again to the branch above to eat the bud, but sometimes consuming it while hanging head downward.

In spring and early summer the red squirrel sometimes cuts off leaves of the sugar and soft maples, eats part of the petiole, and drops the rest of the leaf.

The red squirrel eats the bark of the smaller branches of some species of deciduous trees, especially that of the sugar maple, at all seasons of the year, even in summer when green food is abundant. It is thus not by any means entirely a "starvation ration," as has been supposed, but is eaten apparently merely as a change from other articles of diet. Seton says that in Manitoba: "The third principal food supply is the thinnest greenish outer bark of the quaking aspen or poplar. This it does not store up, but gather as it is needed in time of famine" and Burroughs (1900) says "But the squirrels of this locality evidently got pretty hard up before spring, for they developed a new source of food supply. A young, bushy-topped maple, about 40 feet high, standing beside a stone fence near the woods was attacked and more than half denuded of its bark. The object of the squirrels seemed to be to get at the cambium

layer. The ground was covered with fragments of bark, and white, naked stems and branches had been scraped by fine teeth."

The red squirrel is not a markedly frugivorous species, but occasionally it eats some fruits of various kinds. I have seen it eat the fruits of the wild gooseberry (*Ribes cynosbati*), black elderberry (*Sambucus canadensis*), red elderberry (*S. racemosa*), raspberry (*Rubus strigosus*), bunchberry (*Cornus canadensis*), wild strawberry (*Fragaria virginiana*) and wild rose (*Rosa lucida*), but only on rare occasions. It takes apples more frequently than any other kind of fruit, especially those that are left hanging on the trees all winter, usually biting off and throwing away the skin and pulp and eating the seeds, but sometimes eating some of the pulp. The only case of depredations on cultivated fruits which has come to my attention was reported to me by Dr. A. H. Leim, who told me that at Fergus, Ontario, he has seen this species take strawberries before they were ripe, eating the green side and leaving the riper side, next green gooseberries, carrying them off; then white and red currents, which they ate; then green apples, about one-half grown, which they both ate and carried off.

The red squirrel is very partial to mushrooms of many species, both eating them in the fresh condition and storing them in large quantities. I have seen squirrels eating *Pleurotus ostreatus*, *Collybia radiacata*, *Canthrarellus cibarius*, *Russula* of many species, *Boletus* of several species, *Lepiota naucinoides*, *Morchella esculenta*, *M. conica* and *Clavaria aurea*. Whether the red squirrel eats the poisonous species, such as *Amanita muscaria* and *A. phalloides*, and whether, having done so, disastrous consequences ensue, is a point upon which there are no exact data. I have in several cases noticed large numbers of very fine specimens of *Amanita muscaria* entirely untouched in habitats in which red squirrels were common. On the other hand, one day I saw a squirrel sitting on a fence eating a piece of mushroom which looked much like a piece of *A. muscaria.* When I went close the squirrel dropped the piece of mushroom, and nearby I found a specimen of *A. muscaria* with a piece of very similar size taken out of it. This is at best only circumstantial evidence, and the sequel remains entirely unknown.

Roots of some woodland plants and underground stems are apparently eaten to some extent by the red squirrel. I have seen them digging for something in the spruce forests of New Brunswick, but whether for roots or insect larvae or pupae I could never determine. Osgood (1900) says that in the Yukon "little excavations in the moss show where the Chickarees have been digging for roots."

A peculiar food-habit of the red squirrel was reported to me by Dr. A. H. Leim. In July he saw the squirrels eating the seeds from the heads of timothy (*Phleum pratense*) and orchard grass

(*Dactylis glomerata*) which they could reach from the posts of a fence. Having obtained all those which they could reach from the posts, they started out along the three-strand barbed wires, and from there they got those that they could reach with their mouth or with their front paws. One squirrel, apparently a young one, went out along a wire, swung down, retaining a hold on the wire with its hind feet, caught a head with its front paws, pulled it back, bit it off, and then either raised itself to the wire from which it was suspended or dropped to the wire below. He also observed them jumping from the ground, catching a timothy head, and bearing it to the ground. One squirrel would persist in this occupation for half a day at a time.

The red squirrel at times takes animal food, the kinds most frequently eaten being insect larvae, young birds and bird's eggs. I have seen them eat the larvae and sometimes the pupae of several kinds of insects. Cram (1901) says, "Occasionally you will see one clinging to the side of some dead pine or hemlock, and listening, woodpeckerlike, to the sounds made by the insects at work beneath the surface. When he has succeeded in locating his prey, he tears off the loose bark with his teeth in great ragged pieces, and presently pounces upon and drags forth a flattened white grub an inch or more in length, which he devours with great apparent relish."

That this species eats the eggs and young various species of birds is shown by many data presented in ornithological literature, and this will be referred to later. Personally, I have never yet seen a red squirrel take either an egg or a young bird, and certainly these items constitute an insignificant portion of the food of the average red squirrel.

STORAGE OF FOOD

The red squirrel stores immense quantities of food, chiefly the seeds of conifers, nuts, and mushrooms. During late summer and autumn the chief activity of this species is the storage of food. It also stores food temporarily at all seasons of the year.

This species practices three methods of storage: carrying things off to one of its main hoards, burying each object separately, and arranging them in a fork of a tree. Food materials are pretty definitely classified into two categories: hard objects and soft. Hard things, such as nuts and seeds, it either carries to one of its storehouses or buries; soft things, such as fungi, fruits or pieces of meat, it arranges about the branches of a tree. Thus it does not bury or put in piles anything which will mold or decay readily.

The squirrel's main hoards are made either in cavities in trees or stubs, or in vaults underground, beneath the roots of a tree or a stump, or under a bowlder. It has several such storage places, and, as

far as I have observed, when a squirrel is storing a number of things consecutively it takes them to two, or more, of these hoards alternately.

In the case of both cones and nuts the squirrel cuts them from the trees just before they are fully ripe. This is necessary in the case of most cones (the main exception being those of the hemlock) as the seeds are shed as soon as fully mature, but the same necessity does not exist in the case of nuts. But as Seton says in speaking of the cutting-down of chestnuts before they are fully ripe: "The explanation lies in the fact that the red squirrel has been evolved to prey on the seeds of conifers. If these are left to ripen fully they take unto themselves wings and fly away, whereas by cutting the cone just before it opens the squirrel makes sure of the prize."

Bell (1898) says, in connection with the harvesting of the cones of the white spruce in the north:

> Their mode of obtaining a supply of cones is ingenious. The cones grow principally at the tops of the spruce trees, and the largest and finest are always to be found there. The Chickaree selects a tree which, either because of the steepness and density of its upper parts, or because of its leaning to one side, makes it certain that the cones, if detached, will fall to the ground; then he cuts off the heavily-laden branches and lets them drop. This is done with an impatient rapidity. These branches seldom lodge in the branches below, but should a squirrel on his way down notice one of them in a hopeful position toward the extremity of a bough, he will sometimes run out and give it a second send off.

Professor J. N. Gowanloch informs me that at Gimli, Manitoba, the red squirrels in August cut the green cones of the balsam (*A. balsamea*). A single squirrel to a tree would spend three hours or more cutting off cones and then in the afternoon would carry off the cones and deposit them in holes under the roots of trees.

Speaking of squirrels harvesting the cones of the white pine Cram (1901) says:

> They begin work late in July, while the cones are still green and solid with the seeds embedded near the center. In the hot July sunshine they hurry at their work, cutting off the cones and tossing them over their shoulders well out beyond the surrounding branches to the ground. Whenever the cone of the twig that supports it is cut or scarred, a drop of glistening, transparent sap oozes forth, turing on exposure to the air to the most tenacious kind of pitch; and it is truly wonderful that the squirrels can manage to keep themselves so clean while engaged in their harvesting. But the majority of them show hardly a trace of pitch, though now and then you will run across one with little wisps of fur stuck together, especially about the face and neck and in the longer hairs of his tail, evidently having been particularly unfortunate or careless in his work. Every little while they descend to the ground to bury the cones they have cut off, two or three in a place, covered with pine needles to a depth of several inches.

Audubon and Bachman (1846) say: "The quantity of nuts and seeds it often lays up in its storehouses is almost incredible. On one occasion we were present when a bushel and a half of shellbarks

(*Carya alba*) and chestnuts were taken from a hollow tree occupied by a single pair of these industrious creatures."

Paulmier (1904), referring to this species in the Adirondacks, says: "Later still, when the beechnuts, which form his staple food, are ripe, he collects immense quantities of them, biting off the yet green nuts, so that they fall to the ground, where he afterwards collects them in heaps and stores them away."

Hahn (1909), speaking of *S. h. loquax* in Indiana, says: "Much of its time is spent on the ground where it gathers acorns and nuts and buries them under leaves and under the soil. Some supplies are stored in hollow trees also, although snow is no hindrance to its finding and securing buried treasure."

Bailey (1918) thus refers to the harvesting of the cones of several species of evergreens in the mountains of Montana:

> Before the seeds are fully matured in the cones they begin to serve as food for the squirrels, and when well ripened the cones are cut from the pine, spruce, and fir trees in such numbers that the woods often resound with their steady thumping on ground and logs. During autumn great numbers of cones are cut off and stored in little pockets or holes in the ground, under logs, rocks, or brush heaps, or in the piles of old cone scales at the base of the feeding trees, where they can be readily found under the deep snows of winter.

Two friends of mine one evening found a red squirrel's hoard of butternuts in a hollow tree in northern Frontenac County, Ontario, and filled a bushel-and-a-half bag with the nuts from this single hoard. They left the nuts in the bag some yards from the tree, and returned with a wheelbarrow the next morning to fetch them. But the squirrel had been there before them, chewed a hole in the sack, and removed every nut to some other storehouse, which they were unable to locate.

The red squirrel buries single nuts and acorns here and there in the soil. When it buries a nut it scratches out a hollow with its fore paws, places the nut therein, shoves it is as far as possible with its nose, and then covers it with a few swift strokes from the right and left with its fore paws. It performs this operation with great rapidity, but does it so well that when it has buried a nut in a location where there is moss and dead leaves there is no trace of any disturbance. In fact upon several occasions I have noted as nearly as possible the exact spot at which I had seen a nut buried, but upon going to the place I was unable to find the nut.

Nuts are sometimes stored singly in the crotches of trees, or wedged under a flange of bark of rough-barked trees. Gibson (1903) has noted this habit, and says. "The shell-bark hickory is the squirrel's favorite storehouse. A quick stroke with axe or sledge will often dislodge numbers of nuts which have been packed away and wedged beneath the bark by these provident little fellows."

Mushrooms are stored in large numbers by squirrels, which hang them in the forks of trees, and I have seen trees which contained as many as 20 mushrooms thus suspended. Dice (1921) reports an unusual case of mushroom storage: "A red squirrel in 1911 had its nest on a shelf in an old cabin north of Tanana (Alaska). This squirrel had collected a great number of mushrooms and stored them on the shelves. Those not entirely dry were spread out separately from the others. Every open can in the cabin was packed tightly with the dried fungi."

Any article of food may be temporarily stored in a crotch of a tree, quite frequently something which the squirrel has partially eaten, and it will return a few minutes, a few hours, or some days later, take it out, and either finish it, or eat more of it and store it again, usually in another place.

The squirrel's highly developed hoarding instinct sometimes renders it a nuisance about the habitations of man. It sometimes makes repeated visits to corn-cribs and carries off considerable quantities of corn, and I have known a squirrel to carry off most of the grains in a small sack of wheat. Gilpin (1870) says, "The winter camps of the loggers become infested with them. The men scarce left their camps for their work then the silent structure is attacked by an army of invaders; every hole, every crack and orifice is pryed into, an entrance is made, and perhaps half a barrel of hard bread has been removed by these pilferers before the men return for the night."

CARRYING CAPACITY

The red squirrel can carry off objects of considerable size and weight. One morning the squirrel that I had under observation entered the pantry through the open window. There it discovered a dish of boiled potatoes, some of which it hid behind cans on the pantry shelves, while it carried the others up the maple and arranged them in crotches. Some of the potatoes which it carried up the tree weighed a quarter of a pound. The heavily laden branches of the cedar which the squirrel cuts from the tree are bulky and quite heavy, and the characteristic method of carrying such an object, the head being held high, is shown in Plate 4, Figure 1.

DRINKING

I have only on two occasions seen a squirrel in the woods drink, once from a pool in a little stream and once at the edge of a temporary woodland pool; but the squirrels which I have had under observation frequently drank quite copiously from a saucer of water, and I have also seen them drink melted snow in the spring. This species frequently eats snow in the winter.

The favorite beverage of the red squirrel is unquestionably the sap of the sugar maple, and in early spring in the maple-beech woods, in the mixed forests, and wherever this tree occurs, they spend a large part of their time drinking sap. They obtain this sap in three ways: From that which runs down the underside of branches which have been broken off by the winds of late autumn and winter, from the holes drilled by the yellow-bellied sapsucker, and from incisions which they make for themselves. The former source of the sap flow is by far the most important, as a heavy flow of sap often proceeds from the ends of these broken branches, and in availing themselves of it the squirrels hang on to the underside of limbs, both small and large, as shown in Plate 5, Figure 1. In maintaining this position on the under side of large limbs they rely chiefly on their hind legs, and there is a decided outward bend in these legs at the tarsal joint which evidently enables the claws to catch the crevices of the bark more effectively. When the squirrel hangs from a small branch, both fore and hind feet are clasped about the branch, so that the toes nearly meet on top of the branch.

Stone and Cram (1902) refer to the incisions which the squirrels make for themselves: "In tapping the maple they gnaw saucer-shaped cavities in the upper side of a branch and drink the sap which fills them, coming back a dozen times a day for the sweet refreshment." I have occasionally seen squirrels thus engaged.

In drinking sap they lap it up, their tongues going at a tremendous rate. They also lick the icicles of sap which have formed during the night.

WASHING

After eating anything sticky or greasy the squirrel licks its fore paws very thoroughly, and then rubs them repeatedly over its nose, often spending five minutes thus cleaning up.

SCRATCHING, COMBING, AND RUBBING

During autumn and winter the squirrels which I have had under observation did not seem to be much troubled by external parasites, but toward spring they had a busy time with them. They scratched and bit themselves frequently, and often for some time at a stretch, causing the shedding hair of the winter coat to fly in all directions.

The red squirrel often rubs its jaw and throat along a limb, in this respect reminding one very much of the actions of a cat.

This species not infrequently combs its tail; in doing this it sits up, brings its tail forward between its hind legs and runs the hairs through its teeth.

ENEMIES

The chief enemy of this species in the northern woods is the pine marten, whose climbing ability and agility in the trees equals that of the squirrel. Both in the north and further south, weasels and hawks and owls are the red squirrels' enemies. Fisher (1893) lists the goshawk, Cooper's hawk, red-tailed hawk, red-shouldered hawk, broad-winged hawk, and barred owl as including this species among their food.

RELATION TO GRAY SQUIRRELS

Wherever the red and the gray (or black) squirrel inhabit the same territory the red always chases the gray and the latter runs without putting up a fight, though it is nearly twice the size of its fiery pursuer. A report which has wide currency among trappers and hunters is that the red squirrel castrates the gray. Seton says that this is "an ancient, picturesque, and sanguinary myth," and I was of the same opinion until I was told by Prof. Manley Baker that he had actually seen a red squirrel seize the scrotum of a gray squirrel, and tear it open, on at least a dozen different occasions. He did not think that the act was the result of a deliberate attack for that purpose, but that the red squirrel seized and hung onto the most posterior part, aside from the tail, of the fleeing gray squirrel's anatomy. Professor Baker also stated that he had shot more than 40 gray squirrels which had been castrated.

RELATION TO BIRDS

There is plenty of data in ornithological and mammalogical literature to prove that the eggs and young of many species of birds are destroyed by red squirrels. Merriam (1884) says: "I have myself known him to rob the nests of the red-eyed vireo, chipping sparrow, robin, Wilson's thrush, and ruffed grouse, and doubt not that thousands of eggs are annually sacrificed, in the Adirondack region alone, to gratify this appetite." Mearns (1878) says that the red squirrel is the worst enemy of the robin, and many other writers cite cases of depredations on robins' nests. Seton mentions a case of a red squirrel eating a young flicker. B. S. Bowdish, in a letter which was the only response I received to a note in the Journal of Mammalogy asking for first-hand information on the destruction of young birds or bird's eggs by red squirrels, says:

> I had, about 15 years ago, an experience in personally seeing a red squirrel enter a bird house on a pole, bring out a third-grown young bluebird, and sitting on the roof of the house, open the bird's skull and devour the brains, throwing the body to the ground and repeating until the family of young bluebirds had all been destroyed. I have watched a nuthatch building a nest in a cavity, and a week or so later, found the same cavity occupied by a squirrel's nest with the intruder in possession thereof.

Nelson (1918) says: "During the breeding season he spends a large part of his time in predatory nest-hunting and the number of useful and beautiful birds he thus destroys must be almost incalculable. One close observer believes that each squirrel destroys 200 birds a year."

The passages cited above, and many others of similar purport in ornithological literature, would lead one to believe that the red squirrel is a serious menace to bird life. But there is another side to the picture. Seton says: "Nevertheless there is a remarkable individuality shown among squirrels in this particular. A family of five lived in a grove of six or seven small trees near my house. In this grove a yellow-throated vireo reared her young under the squirrels' very noses. They must have seen the birds, yet did them no harm. William Brewster has described to me a similar case in which he saw the squirrels leap daily over a robin's nest, but offer no harm to the eggs or the callow young." Thoms (1922) under the title "Are Squirrels Bird Enemies?" answers this question in the negative, citing a case of a red squirrel pouncing on a mourning dove on her nest and when she flew off eating the eggs, and of a squirrel throwing young orioles out of their nest, as the only two cases of squirrels molesting birds in his ornithological experience of 20 years, and concludes that "depredations perpetrated by red squirrels do not lessen in any appreciable degree the number of birds." Cram (1901) says, "The red squirrel has been generally accused of being an inveterate robber of birds' nests, and I am afraid there is a good deal of ground for the accusation; still, I have never observed him plundering a nest, nor do the small birds generally exhibit any great alarm or anxiety at his presence in the proximity of their homes." To this I can add that in 25 years ornithological experience, and in 8 years rather intensive study of the red squirrel, I have not come across a case of depredations on nests by squirrels, but on the other hand I have seen three cases where broods of robins were successfully raised in places which a red squirrel visited every day.

Summing up this matter, the facts appear to be as follows: The red squirrel does, more or less frequently, eat both birds' eggs and young birds. People who happen to witness such attacks are usually interested mainly in birds, and often especially in the particular pair whose nest is raided, so that the occurrence makes a deep impression. Any such estimate as "each squirrel destroys 200 birds a year" is, to say the least, a gross exaggeration, as at this rate the number of birds in localities where squirrels are abundant would be seriously reduced, which is not the case. Birds and squirrels have existed together in North America long before man came on the scene, and the settlement of the country has not rendered conditions more favorable to squirrels and less so to birds, but, if anything, the other way round. It is

probable that only certain red squirrels are bird-eaters, just as only certain tigers are man-eaters, and such individuals should be destroyed as soon as evidence against them is obtained.

Another phase of the relation between squirrels and birds is that hawks and owls prey on the red squirrel, as has been mentioned in the section on enemies.

A third phase of this relationship is that some birds, such as the white-breasted nuthatch, downy and hairy woodpeckers, bronzed grackle, blue jay, and house sparrow, rob the red squirrel of the food it has stored in the forks of trees. Both the squirrels I have had under observation lost a large part of their stored food in this way, not so much because most of the food was eaten by the birds, but because the birds in attempting to eat it knocked piece after piece of food out of the forks. Both these squirrels were frequently called upon to defend their stores against these marauders, and when two or more of the birds came into the tree at once they had a very busy time, chasing first one and then another. In chasing these birds the squirrels showed wonderful agility, and many times could, I believe, have caught one of the birds if they had so desired, but in such cases they always jumped short so as not to actually alight on the bird.

Cram (1901) mentions another phase of the squirrel's relation to birds. He says:

> I have never known him to take part in the general outcry against a hawk or owl. . . . But let him catch a glimpse of an unoffending partridge quietly gathering berries or scratching among the pine needles, and he immediately pretends to fall into an utterly uncontrollable rage. He slowly approaches the bird with short, scratchy starts, down the tree trunk, keeping on the opposite side as much as possible, and peering out from behind the rough bark and protecting branches, as if fully aware of his danger and determined on not exposing himself more than necessary, and ever and anon retreating panic-stricken, back into the shadow, to renew the attack from an opposite direction, barking huskily. . . . It is wholly out of the question to suppose for a moment that he can have any cause for resentment against the grouse family; and yet, so universal is this habit of scolding and threatening them on every occasion that I find I have gradually fallen into the way, when shooting grouse, of allowing the squirrels to point out my game for me to a certain extent, finding that three times out of four I can tell from the way they chatter whether or not it is a grouse that excites them at the time.

A unique case of the relation of squirrel and bird is that recorded by Roberts (1922) who saw a titmouse gathering hairs from the tail of a red squirrel while the latter organ was hanging down from the crotch of a tree. The titmouse "flew down, perched on the trunk beside the tail and gathered herself a mouthful of hairs, the squirrel seeming to pay no attention. At first I thought that the squirrel was dead, but when I started to walk around the tree he kept himself on the other side as usual. The titmouse followed him around, took

a few more hairs and flew away, only to return in a few minutes for more."

RELATION TO FORESTS

The activities of the red squirrel which might be assumed to have an injurious effect upon the forest are: The eating of immense quantities of seeds of conifers and nuts, the eating of buds, and the barking of trees. As regards seeds and nuts, there is an immense overproduction as compared with the number which fall in situations where they can germinate, and a very much larger number of young trees start than can ever reach maturity, so that there is no evidence to show that squirrels, by their seed and nut eating proclivities, in any way interfere with forest reproduction. The eating of buds, even when, as in some cases which I have witnessed, it seems to be rather drastic, does not have any injurious effect upon the trees. The amount of bark which is eaten from any individual tree is usually small, and a branch is girdled only in exceptional cases, so that the aggregate injury from this cause is small.

On the other hand there is little doubt but that the red squirrel plays a more or less important part in reforestation, by reason of the germination of seeds and nuts which it buries in the soil—thus bringing them into the most favorable situation for germination—and then either forgets or does not need.

PSYCHOLOGY

In the study of any animal the most interesting thing, and at the same time the phase of the subject in which we have to proceed most cautiously in drawing conclusions, is its mentality. I shall not enter here into a discussion of the complications which the study of animal psychology presents, of the pitfalls for the unwary with which it abounds, or of the hotly debated matters of instinct, intelligence and reason as shown by animals other than man, but shall merely remark that I am familiar with the methods and with the results which have been attained in comparative psychology, and that I believe that close and long-continued observation of red squirrels has given me some glimpses of the mentality of this species.

GENERAL TEMPERAMENT OF THE SPECIES

Every species of animal exhibits, after one has a sufficient acquaintance with it, a general temperament, which, in spite of individual exceptions, is characteristic of the species. The main outstanding features of the temperament of the red squirrel are: First, vivacity; and second, the ability to "keep its head," that is, not to become panic-stricken in times of danger.

INDIVIDUALITY

This species exhibits individuality in a marked degree—in general behavior, in actions, poses, food preferences, in fact in every particular in which we can detect individuality in an animal.

An excellent example of individuality was related to me by Dr. J. G. Needham who stated that a certain red squirrel developed the habit of eating the terminal buds, both apical and those of the branches, of spruce trees about his house, and in this way damaged the trees so much that it had to be shot. No other squirrels, of which there were several on the property, exhibited this habit.

CURIOSITY

Curiosity is an attribute which the red squirrel exhibits very prominently. Any new object is at once seen, carefully approached and investigated. It seems as if the squirrel's method of investigation involves not only smelling a thing but trying it with its teeth.

OWNERSHIP

The sense of ownership seems to be well developed. Both of the squirrels which have made the maple in my garden their headquarters apparently regarded this tree as their private property, and drove away other squirrels which came into it. It is quite likely that in this case it was not the tree, but the stores that were arranged about it, which they were defending. When the first squirrel was the "owner" of this tree, another male, a little larger and apparently as strong, sometimes came into the tree. It was immediately attacked, and fled, hotly pursued, without putting up a fight. Once I saw the intruder come into the tree while the "owner" was away, and finding some pieces of meat it proceeded to eat them in such a hurry that it choked. The behavior of a red squirrel which is raiding the stores of another is so absolutely different that one can tell at once that it is not the owner.

The ownership of an article seems to be marked upon it by the squirrel licking it, and by its moving it from the place in which it is found. I have noticed again and again that when a squirrel finds something for the first time it licks it, but when it takes out something which it has had in temporary storage it does not do so, and that a thing when found *must* be moved, even though it is moved only a foot, or sometimes even six inches, and the movement does not result in a better storage place.

MEMORY

The red squirrel has an excellent memory. This is shown chiefly by the way it remembers where it has put things, even after they have been stored away for several days. Its location memory is, it seems to me, phenomenal. Time after time I have seen it go by the nearest route to something it has stored, take it out, and eat it. I have seen it go to the ground and retrieve nuts when there was to my eyes no evidence that a nut was buried there. The most conclusive proof of the strength of its location memory was given by an incident in the winter of 1924–25. The squirrel had buried nine nuts in the snow on the balcony one afternoon. During the night there was a heavy snowfall, and the new snow lay over a foot deep on the balcony. Next morning the squirrel came, went without hesitation to each place, dug down, and successively brought up the nine nuts. In many cases there is a possibility that the sense of smell may play a part in the finding of objects, but in the last case cited this seems to be out of the question.

ANTICIPATION

Anticipation is dependent upon, and directly connected with, memory, and involves the association of ideas. I have seen several instances of anticipation by the red squirrel. On two occasions I saw a white-breasted nuthatch come and peck at a piece of food which the squirrel had stored in the tree; the squirrel drove the bird away, and then, as the nuthatch flew, the squirrel bounded over to another piece of food as if it anticipated an attempt on that piece also. I have also seen it bound over to guard something as soon as the nuthatch came into the tree. Once, after we had been away for a few weeks, the squirrel, as soon as it saw us at the balcony door, immediately went over to a limb on which we had been in the habit of placing food. The ability to anticipate and forestall an event was shown by one incident. One day I placed a pile of apple peelings and two small apples on a board which projected out over the roof. The squirrel was pulling at a long piece of peeling when one of the apples rolled and was about to fall off the board. The squirrel dropped the peeling and seized the apple just in the nick of time.

EXPRESSION OF MENTAL STATES

The mental states of the red squirrel are expressed mainly by attitudes, more rarely by the voice. Surprise, fear, curiosity, attention, anger, contentment, all have their characteristic attitudes. The attitude of surprise is either one in which the animal draws itself back on its haunches and allows both forepaws to hang from the sides, or else picks up first one forepaw and then the other. In fear the body is flattened, the head dropped, and the tail held straight out. In curios-

ity the neck is stretched out to a remarkable degree. Anger is shown by stamping the hind feet and jerking the tail; sometimes by stamping the front feet as well. Attention, especially listening, is shown by folding one paw and placing it against the breast, if the animal is on "all-fours"; or bringing both forepaws against the breast, if it is sitting up.

The voice seems to be used only in anger, pain, curiosity, and in intercommunication. The long rolling "Chir-r-r-r-r-r-r-r-r" is an intercommunication note, and is never used unless another red squirrel is in the vicinity.

The scolding chatter, which is so familiar to everyone, seems to indicate anger, and is usually accompanied by stamping of the hind feet, which action is sometimes so violent as to become a veritable dance. It might be assumed that this chattering note denotes only excitement and not anger, but from my observations I am inclined to believe that this is not the case, as the squirrel can become very excited without chattering, but as soon as its wrath is aroused by anything, such as a person, cat, dog, another squirrel, or some activity of its own which has not gone to suit it, it chatters. One incident which brings this out rather well was as follows: I had put out two very hard buns for the squirrel. It had some difficulty in getting a firm grip on one of the buns because of the hardness and large size, but finally made off with it. It ran up the branch from which it usually jumped to the roof of the next house, gathered itself together, and sprang across. But in mid-air the bun slipped and fell to the ground. The slipping of the bun upset the squirrel's leap, but the animal managed to alight safely, though far from gracefully. It looked over the edge of the roof, after the bun, and then chattered and stamped. It soon returned for the other bun, again had a struggle to grip it, carried it up the branch as before, and jumped—with the same result, the bun slipping from the squirrel's teeth in mid-air. After this second failure it was thoroughly angry and chattered and stamped for a long time.

The note of pain is a rather shrill scream. I have heard it from an intruding squirrel when bitten by the owner of the stores it was raiding.

When the squirrel is curious, it often makes a low, "meur-meur-meur" note, and guided by this note I have often been led to observe that a squirrel has discovered something.

REFLECTION

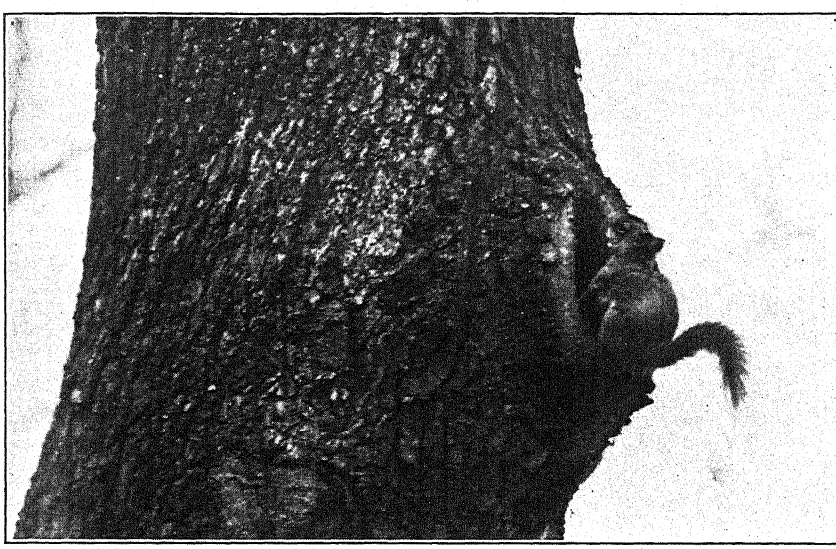
Reflection is a mental attribute which is supposed to be characteristic only of man. Yet if it is not reflection, how else are we to catalogue the mental state which leads to such actions as the following. I have often seen a red squirrel take a piece of food, start for

one place with it, pause a moment, then return and deposit it in some other place. I have also repeatedly seen it store a piece of food in one place, come back a short distance, pause, return to the food, seize it and place it in another location, and I have also seen it return to a piece of food it has just stored in a fork of a tree and rearrange it. As to what actually passes in the mind of a squirrel we are, unfortunately, completely in the dark; all we can do is to draw inferences from its behavior and keep these inferences as far as possible untinged by our own mentality. But from close and long-continued observation I am convinced that the mental processes of the red squirrel are far more varied and complicated than is usually supposed, especially by those who pin their faith to experiments on animals under entirely unnatural conditions.

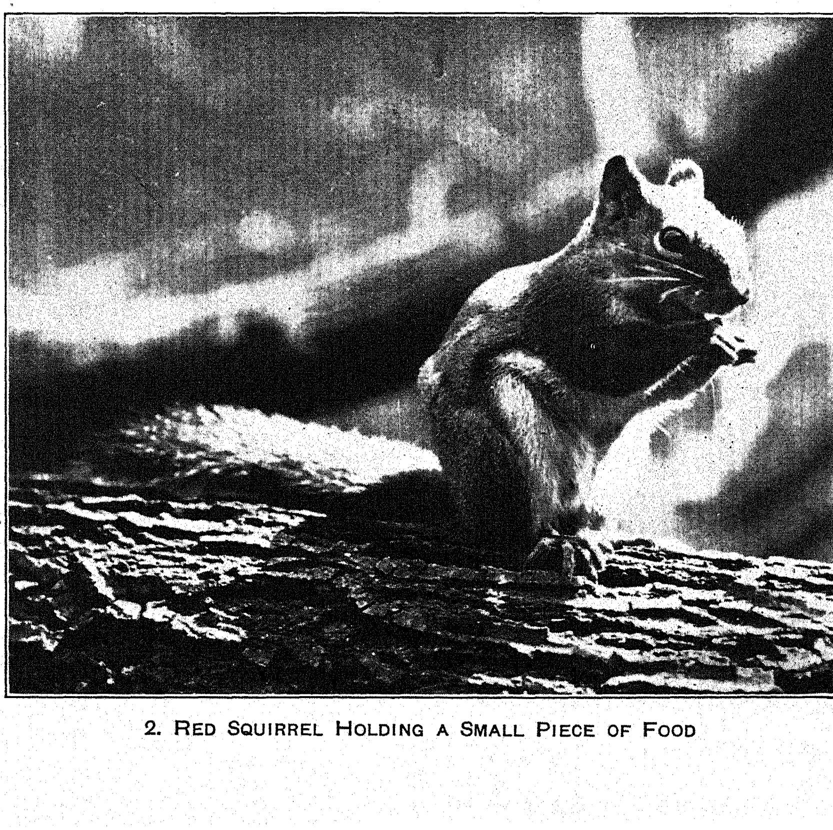
LITERATURE CITED

ADAMS, A. L.
1873. Field and forest rambles with notes and observations on the natural history of eastern Canada.
AUDUBON, J. J., AND J. BACHMAN.
1846. Quadrupeds of North America, Vol. 1, p. 128.
BAILEY, V.
1918. Wild animals of the Glacier National Park. Nat. Park Service.
BELL, R.
1898. Nature and development of animal intelligence (Mills, 1898). Appendix.
BURROUGHS, J.
1900. Squirrels and other fur-bearers.
COLE, L. J.
1922. Red squirrels swimming a lake. Journ. Mamm., Vol. 3, p. 53.
CRAM, W. E.
1901. Little beasts of field and wood.
DICE, L. R.
1921. Notes on the mammals of interior Alaska. Journ. Mamm., Vol. 2, p. 25.
DICE, L. R., AND H. B. SHERMAN.
1922. Notes on the mammals of Gogebic and Ontonagon counties, Michigan. Occas. Papers Mus. Zool. Univ. Michigan.
FISHER, A. K.
1893. The hawks and owls of the United States.
GIBSON, W. H.
1903. Highways and byways.
GILPIN, J. B.
1870. On the mammals of Nova Scotia. Trans. Nova Scotia Inst. Nat. Sci., Vol. 2, p. 8.
GOSSE, A.
1840. The Canadian naturalist.
HAHN, W. E.
1909. The mammals of Indiana. 33rd Ann. Rept. Indiana Dept. Geol. and Nat. Resources, pp. 468–470.
MEARNS, E. A.
1878. Birds of the Hudson Highlands. Bull. Essex Inst., Vol. 10, p. 9.

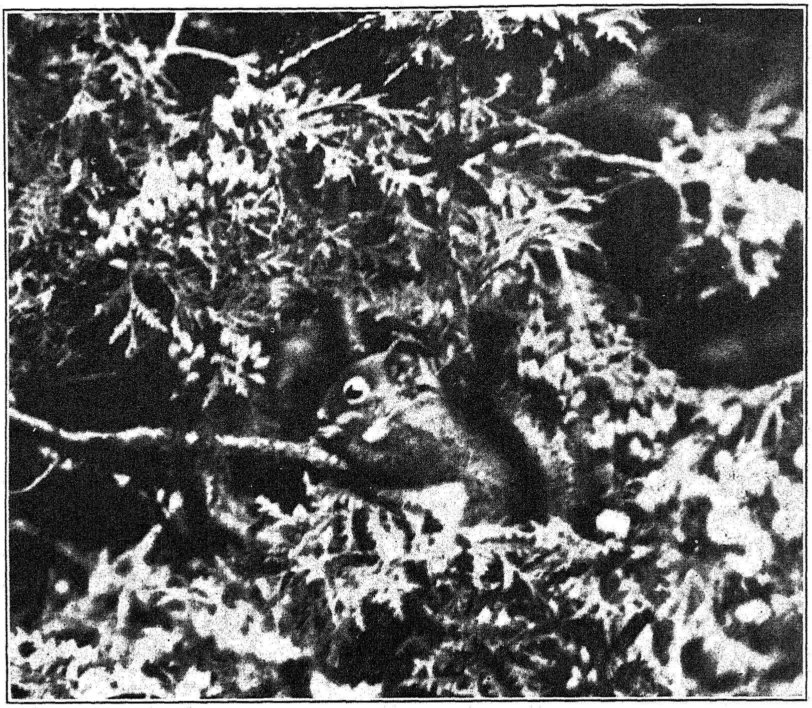
MERRIAM, C. H.
1884. The mammals of the Adirondack region.
MILLER, G. S., JR.
1900. Preliminary list of the mammals of New York. Bull. New York State Mus., No. 33, Vol. 7.
NELSON, E. W.
1918. Wild animals of North America. Nat Geog. Soc., Washington, D. C.
OSGOOD, W. H.
1900. Results of a biological reconnaissance of the Yukon River region. North Amer. Fauna No. 19.
PAULMIER, F. C.
1904. The squirrels and other rodents of the Adirondacks. Ninth Report Forest, Fish, and Game Comm. of New York, p. 339.
RICHARDSON, J.
1829. Fauna Boreali-Americana, Vol. 1, p. 187.
ROBERTS, B.
1922. Bird-lore, Vol. 24, p. 215.
SETON, E. T.
1909. Life-histories of northern animals, Vol. 1.
STONE, W., AND W. E. CRAM.
1902. American animals, p. 174.
THOMS., C. S.
1922. Are squirrels bird-enemies? Bird-lore, Vol. 24, p. 207.



1. RED SQUIRREL AT NEST HOLE

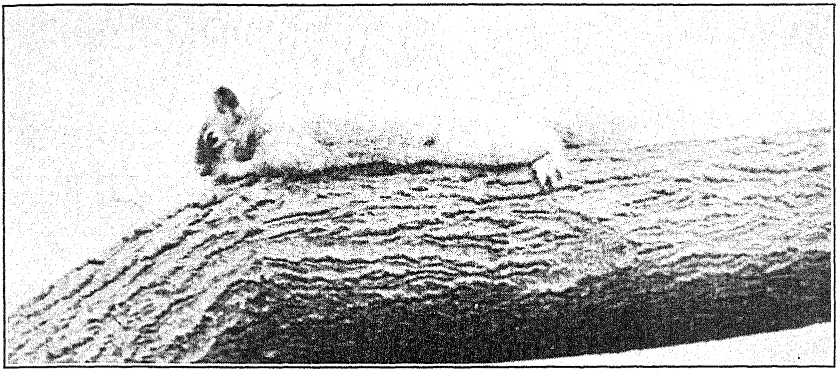


2. RED SQUIRREL HOLDING A SMALL PIECE OF FOOD

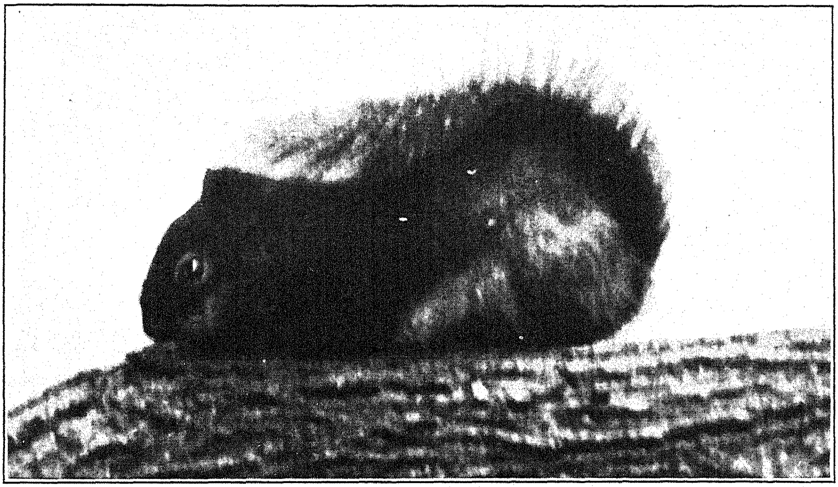


1. YOUNG RED SQUIRREL EATING CEDAR SEEDS

2. YOUNG RED SQUIRREL. CURIOSITY

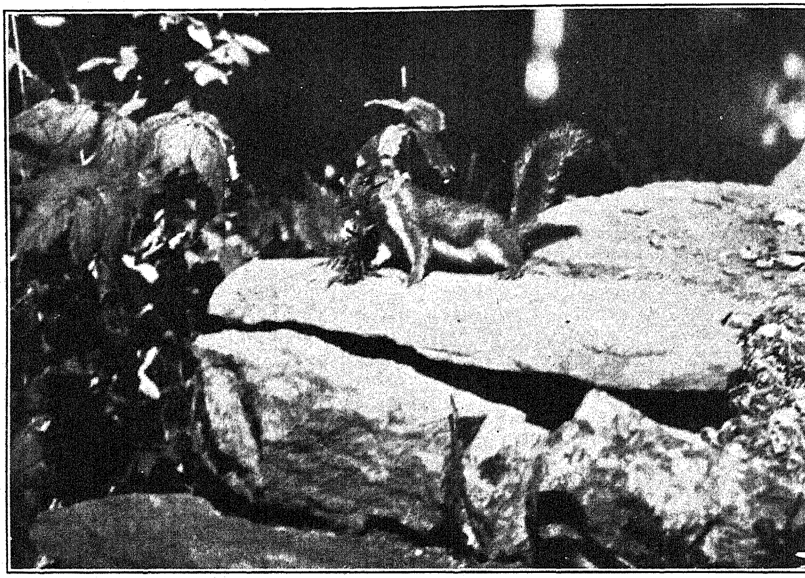


1. RED SQUIRREL RESTING. ATTITUDE 1



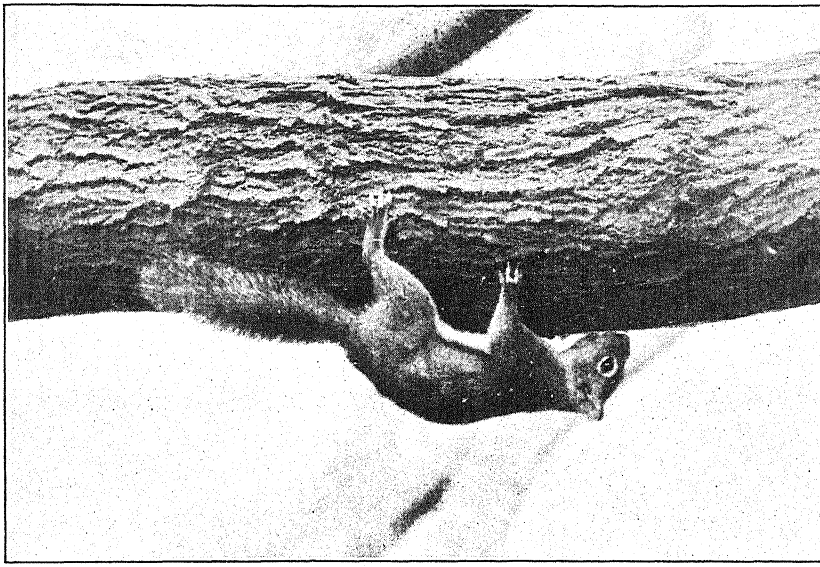
2. RED SQUIRREL RESTING. ATTITUDE 2

3. RED SQUIRREL RESTING. ATTITUDE 3



1. RED SQUIRREL CARRYING BRANCHES WITH CEDAR CONES

2. RED SQUIRREL COMING DOWN TREE



1. RED SQUIRREL DRINKING SAP

2. RED SQUIRREL SMELLING TRAIL OF ANOTHER RED SQUIRREL

SOME ADVENTURES OF A NATURALIST IN THE CEYLON JUNGLE

By Casey A. Wood

[With six plates]

The almost universal longing of the healthy adult to explore a forest wilderness and to lead for a time a forest life is sometimes referred to as a survival of boyhood, but the roots of this impelling force lie much deeper. The call of the wild is probably a revival of memories stamped, many thousands of years ago, on the cerebral cells of our arboreal ancestors. It is a savage inheritance which we may contemplate with pleasure and, unashamed, put to practical use when opportunity occurs, if for no other reason that that given by Charles Kingsley. "Some day, ere I grow too old to think, I trust to be able to throw away all pursuits save natural history and to die with my mind full of God's facts instead of men's lies." For the carrying out of such a plan I offer the jungle of Ceylon.

There are few large islands lying within the Tropics that offer so many attractions to the biologist. This pear-shaped appendage to the Indian peninsula extends its greatest length from 6° to 10° north of the Equator. Its longest measurement is 271½ miles, its greatest width 137½ miles, its area, with dependent islets, is about one-sixth smaller than that of Ireland, or in the neighborhood of 26,000 square miles. The island is quite mountainous, the southern hill zone alone covering an area of 4,200 square miles, while there are at least four peaks whose heights are over 7,000 feet. The climate—a matter of considerable moment for the field worker—is one of the most delightful in the East. Owing to the medium size of the island, to its position in a large ocean of uniform temperature, to the influence of the trade winds that regularly blow over the Bay of Bengal and the Indian Ocean, and to other causes, this terrestrial paradise is free of the extremes of heat and cold that render many tropical countries uncomfortable and unhealthy for natives and foreigners alike.

Again, there is for the visitor generally a choice of altitude and consequently of climate, flora, and fauna. If he objects to the comparatively hot temperature of Colombo, on the low-lying seacoast, he

may move to Kandy (1,600 feet above sea level) where, owing to elevation and other influences, the nights are cool (occasionally cold) and where the mean temperature of each month in the year rarely deviates more than a single degree from 76° F., the mean annual temperature.

If, however, the naturalist desires a change of study and still cooler surroundings, let him move to the summer capital, Nuwara Eliya, 6,500 feet above sea level, where he may enjoy all year round the conditions and appearances of a New England spring. Although he will never anywhere in Ceylon see snow, the evenings and nights at this elevation are quite cold and fires, overcoats, and blankets are among conveniences not to be despised.

Ceylon, thanks to British enterprise and good government, is gridironed by excellent motor roads. They, in conjunction with the railways, provide access to all parts of the colony, even to out-of-the-way jungle and mountain areas. This provision renders field studies of its flora and fauna comparatively easy tasks, and if the student of nature will avoid alcoholic beverages, is careful to eat only well-cooked food and ripe fruit fresh from its protective coverings and to drink boiled or bottled liquids he can laugh at the dysentery, typhoid fever, and similar ailments that may affect the careless and improvident in any country.

With this regulation of diet the only disease likely to attack the visitor to the Ceylon jungle is malaria. That danger may be nullified by sleeping always under a well-made and untorn net, after one's servant (better, do it yourself) has carefully inspected the bed and the interior of the net to make certain that all mosquitos in them are killed. Remember this rule of the jungle applicable in all malarial countries: Protect yourself from the deadly female anopheles, that winged serpent that between sunset and sunrise seeks whom she may devour. Eliminating this danger one may freely explore the wildest Sinhalese forest with little discomfort and with slight danger to life and limb.

My first lesson in wild sylva was provided by the environs of Kandy. The borders of the lovely little lake that forms its center are embellished by a dozen of the most beautiful flowering species in the whole world. A walk of three or four miles about that lacustrine, park-like area furnishes a liberal education in tropical botanical life. If one wishes to take a further course in this fascinating subject, a few miles away are the beautiful gardens of Peradiniya and Hakgalla.

Nor is the study of jungle zoology less restricted; to acquaint oneself with the birds, mammals, and reptiles of this charming country may well occupy several years of one's lifetime. In the few pages at my command I shall, of course, be able to speak of but few of the

plants and animals that make up the life of the Lanka Forest, but of all the jungle areas I have visited throughout the Tropics it has charmed me most.

The birds peculiar to Ceylon are now being pictured from drawings[1] by Mr. G. M. Henry and as this beautiful atlas is issued by the Government at a very low price I shall say nothing further about them.

Of all the nest-builders the Indian tailor bird (*Orthotomus s. sutorius*, also known as *Sutorius s. sutoria*) holds first rank. In the Smithsonian Annual Report for 1925 I thought I had described all the typical nests but a glance at the accompanying plates will show my error. Additional studies of these wonderful structures convince me that nidification forms are almost endless. Indeed, the finest example of the sewing, stitching, and suturing these little birds are capable of was sent me a short time ago by a lady in Kandy. It is made of four hibiscus leaves—probably *H. rosa-sinensis*—three of them fairly large and in their normal site on the tree, and the fourth smaller, inverted and used to fill the space between the others. Roughly, the nest mass is 6½ inches long, with transverse diameters of 3 and 3½ inches, respectively. The opening at the upper part of the nest is quite patent and must have been readily reached by the birds.

Miss Le Marchant, of Kandy, who discovered and gave me this example, tells me that it was built about 4 feet from the ground and was entirely hidden from view. The body of the nest is well filled with the floss of Kapok (*Eriodendron anfractuosum*) or "silk cotton," mixed with papyrus-like bark, vegetable (coconut?) fibers and a few hairs. The nest cavity extended to the very bottom of the structure and was carefully lined with kapok over an intertwining layer of fibrous material. The tailoring was mostly of the tufted pattern, although here and there are evidences of genuine sewing and stitching.

Mr. N. K. Jardine of the Ceylon Department of Agriculture recently noted an interesting instance of parasitism in this species which is unique in the literature. As soon as a Loten's sunbird (*Cyrtostomus lotenius*) had completed a nest, a pair of tailor birds took possession. The female laid one egg therein, hatched it and raised a fledgling. Was this a case of pure laziness on the part of the birds, or had they failed in one or more previous efforts at nidification and, weary of the fruitless struggle, decide to rent and not to build? Who knows?

During my sojourn in Ceylon I found it politic to offer small rewards for gathering such plants and animals as I could induce the indolent natives to collect. Among desiderata were nests of the In-

[1] Colored Plates of the Birds of Ceylon, 3 parts, 48 colored plates. Dulau & Co., London. 1927.

dian tailor bird and although I never was made richer by a single nest I did secure several quite similar dwellings of the tailor ant (*Oecophylla smaragdina*). The ecology of this wonderful insect might fill a book. He does not sew but glues the edges of leaves together, afterwards lining the cavity, not with cotton or other fibre, but with a kind of self-made transparent paper which is also used for joining the leaf edge. Many a time I have watched these industrious architects at their work. The object of their house building is to form a globular casing in which the breeding cells, food, etc., are stored. First, several ants stand on the margin of one leaf and, grasping a contiguous leaf edge in their mandibles, draw it to the border on which they are standing. Other workers on the inner or opposite surfaces paste the approximated margins together.

If the neighboring leaf is too far away the ants make a chain of their bodies to reach the desired contiguous blade which is then drawn up and cemented. This work is so thoroughly done that long after the leafy materials have dried and are partly disintegrated the original structure holds its shape and a good deal of force is required to tear it apart.

It is advisable to make these observations at a safe distance because the red leaf ant is one of the largest and most ferocious of its order; its bites are very painful and, for some persons, poisonous. Examined with a lens their crossed mandibles show serrated edges; they may be said to be armed with veritable "teeth." I have had them drop on and bite me while walking along a jungle path. No native will ascend a tree for coconuts, toddy, or other objects when there are active colonies of red ants on trunk or branches.

It is only fair to say just here that many of the animals one has been taught in school books to fear are those that in Ceylon, at least, give the working naturalist little concern, while others with whose habits he is less familiar call for some consideration.[2]

In the first category may be placed four or five poisonous snakes, the elephant, the leopard, the crocodile, the wild boar and, perhaps, the bear. I shall have something to say about my experiences with these later on.

Of the really dangerous animals, as one meets them in jungle life, there are, in addition to the deadly Anopheles just mentioned and which I regard as incomparably the most lethal of all Ceylon animals, mainly three. The chief of these, so far as my experience goes, is also invertebrate, viz: the Ceylon land leech. Two other danger-

[2]Among the native population the figures vary, but in an early quinquennial report of 108 coroners' inquests on deaths from wild animals, 68 (mostly women and children) were from serpent bite; 16 from elephants; 15, buffaloes; 6, crocodiles; 2, wild boars; 1 by a bear. This can hardly be called excessive in a native population (for the period quoted) of over 2,000,000, mostly forest residents.

ous animals are the buffalo (both wild and domesticated) and the "rogue" elephant.

There are other Sinhalese animals one encounters in the jungle that the naturalist had better not associate with too intimately (the crocodile, for instance) but considered as dangerous to health or life they are negligible.

During a residence of more than two years in Ceylon, when I made many excursions over the island, I never saw but one wild cobra, and yet there is no doubt but that *Naja naja* is not an uncommon reptile in all parts of the colony. Wherever I went I was continually on the lookout for this interesting ophidian, but I saw him in numbers only as caged specimens.

I knew that none of the so-called "king cobras" infests the country; the Hamadryad *Naja hannah* is not found in Ceylon. That fierce and dangerous serpent is a purely Indian species of quite another variety, whose distinguishing character is that he is not only unafraid of man but, unlike the hooded cobra, will chase and attack human beings on the slightest provocation.

I met in Colombo an engineer just returned from a tour of inspection in the interior of Burma. One day, while driving through a lonely jungle, he stopped to turn his small car and saw ahead of him a snake in the middle of the road, coiled and hissing. He recognized a large king cobra with whose evil disposition he was well acquainted, so without further ado he proceeded to turn tail and run, but not before the venomous reptile was upon him, striking at the moving car and trying to board it. However, he was finally able to get away in time and escaped, leaving the cobra well behind. Similar tales by reliable observers I have heard first hand from several other people. On the other hand, the Ceylon cobra is practically harmless and unless actually trodden upon or otherwise badly frightened will not attack man, and will almost always try to escape.

During one of my jungle excursions I was taking a midday siesta when my servant came in breathless, "Master, master, a snake." I followed him through the little village near which we were camped and accompanied by, it seemed to me, all the inhabitants, male and female, babies and ancients, we reached a spot a hundred yards or so in the deep jungle and there, in a tamarind tree (a most ususual resort for a terrestrial snake) was a cobra of unusual length—perhaps 6 feet. My entourage, including my servant, kept a safe distance, but as I knew the snake's attitude toward humanity I got fairly close and with my glasses studied him to some purpose. Soon he tired of us, and, slowly crawling through the foliage, disappeared. As all my native friends were Buddhists, Naja was safe from them; as for me, why should I shoot an animal practically innocuous that was doing its duty in regulating the balance of amphibian life?

I can not draw such a peaceful picture of the dreaded tic-polonga (*Vipera russelii*), a beautifully marked, viperlike snake with typical poison fangs of the hypodermic-syringe type.

This snake has a bad habit of lying *perdu* on or near paths frequented by village inhabitants. He is not so good tempered as the cobra and is likely to strike the passer-by. A friend of mine had a narrow escape in this way. Walking home from our hotel a tic-polonga, easily recognized by its variegated, striped skin, struck at him from a neighboring bush and caught the sleeve of his coat. He shook off the reptile, which escaped into the shrubbery.

The roster of death from poisonous-snake bite in Ceylon is not a long one, and rarely includes a European name. I could not find an account of a single death among the white race from this cause during my stay in the country. I suspect that the wearing of boots, shoes, and heavy clothing has much to do with this record. It is the barefooted, half-naked, and therefore unprotected native who suffers.

Speaking of the land leech, I have already drawn attention (Ann. of Med. Hist., 1926, p. 441) to the fact that I have on several occasions been successfully phlebotomized by this active little beast during my jungle trips and can testify to its efficiency as a letter of blood. I did not, however, dwell upon the chief danger of the bites from the several hundred "teeth" of this wicked little creature, viz, the secondary infections, ulcers, etc., that follow the triangular incisions made by them unless the wound is promptly and effectively treated—after the copious and persistent blood-flow is arrested—by iodine and collodion.

One meets with this leech everywhere on the island where the rainfall is sufficient. It is an agile and exceedingly nimble little animal, from 1 to 1½ inches in length. Attached by a posterior sucker to the top of a grass stem or exposed leaf, it lies in wait, waving about in the air with eyes and smelling apparatus alert, awaiting the passage of its warm-blooded victim. The bite is not painful, but the incision bleeds freely; indeed the first intimation the host generally has of his visitor's insult is a stream of blood trickling from the point to which the leech has attached itself.

It is not possible to speak of Ceylon leeches without thinking not only of their medicinal but of their important military and political relations. One of the chief defenses of the ancient Kandyan Kingdom, and one explanation of its successful resistance of foreign invasion for 300 years after the subjugation of the rest of the island, lies in the vast multitudes of leeches that infested the wet, impassable mountain jungle that lay between the seaboard and Kandy, and through which an invading army must march. As one of many such incidents, in 1553 A. D. a force of Portuguese soldiers, on their way

to attack the Kandyan king,[3] "were encamped in the midst of rank grass and marshy pools infested with myriads of leeches. Clothes afforded no protection against their needlelike bodies; satiated, they dropped in streams of blood from the eyelids and ears of the men, and had to be plucked out of their very gums as they ate their food. Rest was out of the question, for the voracious animals swarmed on all sides in ever-increasing numbers." The expedition failed of its objective.

I have always had a salutary fear of herds of water buffalo, even of those individuals who have not made something more than a passing acquaintance with Europeans. The Sinhalese form does not differ from the other oriental carabaos. They delight in immersing themselves in any of the thousands of tanks that constitute the wonderful irrigation system of ancient Ceylon; or to lie for hours covered with mud and, while thus protected from stinging insects, the helpful crow picks from their smooth, leathery backs the ticks that burrow in their skin.

This buffalo hates the smell of the stranger, especially of the white "outlander," and *may* attack him head-on unless he is able to escape, preferably by climbing some friendly tree. Seventy years ago Tennent painted a vivid picture of the habits of this dangerous brute, particularly when he was encountered in the unfrequented solitudes of Ceylon. He speaks of the temper of the wild (let me add that some domesticated animals should be included) buffalo of Ceylon as morose and uncertain and said that "it is never quite safe to approach them if disturbed in their pasture or alarmed from their repose in the shallow lakes. On such occasions they hurry into line, draw up in defensive array with a few of the oldest bulls in advance, and, wheeling in circles, their horns clashing in a loud sound as they clank them together in their rapid evolutions, they prepare for attack, but generally after a menacing display the herd betakes itself to flight. Then forming again at a safer distance they halt as before, elevating their nostrils, and throwing back their heads to take a defiant survey of the intruders."

There remains the "rogue" elephant as a real danger to the tourist in Ceylon, but before recounting my experience of this rather curious animal anomaly, let me say something about the interesting Sinhalese elephantine race, which differs in many respects from their cousins, the Indian and African species.

Before visiting Ceylon I, in common with most naturalists, believed that I knew something of *Elephas maximus maximus* of Linnaeus, but more or less intimate contact with that animal proved how ignorant I really was. A few of these observations may interest the reader.

---

[3] PIERIS, P. E. Ceylon and the Portuguese, p. 72.

The Ceylon race of elephants was at one time found in immense numbers all over the island, even at the tops of the high mountains, wherever food, shade, and water were obtainable. The inroads of man have since then greatly reduced their numbers and limited their range, but they still are found wild in many accessible localities. I have often found their fresh spoor and seen recently captured specimens during my forest rambles.

This historic subspecies has been exported especially to India from the earliest times. Aelian, the naturalist historian, writing in the second century A. D., gives an account of their employment in the first Punic War. In more recent times all wild elephants became the property of the Kandyan kings, and their capture without permission of the crown was a grave criminal offense.

Doubtless the survival of comparatively large herds of Sinhalese elephants is due chiefly to their lack of tusks. While the Indian and African elephant—both male and female—possess this important source of the ivory of commerce, less than 1 per cent of the Ceylon variety—invariably the male elephant—is provided with these useful organs. Their place is taken by undeveloped tushes about a foot long which assist the animal to gather his food or to dig in the earth for water, or to uproot succulent plants. The tusks of the Sinhalese elephant are quite unlike those of his African relative, being smaller, more slender, more gracefully curved and furnishing less than one-half the ivory of the latter species.

With rare exceptions I found the Ceylon elephant to be a most intelligent, harmless, amiable and useful beast, readily tamed and, if properly treated, able and willing to do a certain amount of hard work.

His habits in the jungle are well known. As he fears no enemy but man and as his food is everywhere easily obtainable, there is no rivalry with other denizens of the jungle and consequently no development in him of combative qualities.

In addition to the absence of tusks, the ears of the Ceylon variety are smaller than in the Indian and African species, the forehead is higher and more concave, and the formation of the teeth is different.

When in India I had an ancient illustrated Sanskrit manuscript on the elephant translated for me. It corresponds to a similar work in Pali-Sinhalese, called the Hastisilpe, in which the various breeds or castes of this noble animal are carefully described and pictured.

Apart from the white or albino elephant the natives of Ceylon prefer to the usual, uniformly light-brown animal one whose skin is disfigured by yellowish, pink, or flesh-colored blotches, especially on the trunk, ears, forehead, and legs. These mottled areas do not indicate a particular breed but are very likely deteriorations of

the cuticle produced by the healing of local sores or abrasions caused by rubbing the irritated parts on the rough bark of trees.

It has often been noticed that the derma of wild elephants is of a lighter brown than that of captives, a condition probably due to the care given tame animals. The latter not only receive frequent baths but are as often shampooed with a brick, a coconut husk, or a piece of burnt clay. This treatment, with an occasional application of oil, probably accounts for the darker coloration of the skin in tamed specimens.

I was not able to verify, in the case of Sinhalese elephants, any of the travelers' tales about the dread or fury supposed to be incited in the elephant by the presence of smaller animals, the dog, the pig, the mouse, the horse, etc. I am convinced that so far as the Ceylon race is concerned he does his best, consistent with his love of solitude and family life, to live in peace and amity with all other animals. If he attacks horses and dogs his animosity does not arise from any dislike of them per se but because of their well-known association with his arch enemy, man.

That tame elephants do not fear or dislike horses is of common knowledge in Ceylon; indeed the contrary is generally true. Horses evince a decided dread of the elephant. While I was living in Kandy the acting governor and some members of his family were one day riding along a mountain path, when they met a working elephant, ringing his warning bell as he moved about. All the horses of the party bolted and the governor with his half-crazed mount fell over the mountain side. The horse was killed, but his rider fortunately escaped with some injuries.

During the rutting season—called in Sinhalese mudda—elephants are subject to fits of temporary paroxysms of fury when it may be dangerous for even the animal's mahout to approach the gentlest or tamest of them.

The Sinhalese elephant does not depend upon his trunk or tushes as weapons of defense, although he may occasionally use them for that purpose. Butting with his ponderous head and utilizing the enormous crushing force of all four legs he holds the smaller animal with his trunk while he endeavors to tread the life out of him by alternate tramplings with his enormous feet.

The elephant has weak vision and a poorly developed ocular apparatus. As in the dog, this defect is neutralized by his acute hearing and highly developed sense of smell. Indeed his eyesight would not be of much use to him when surrounded by the close foliage of the jungle even if his thick and almost rigid neck did not materially limit his range of vision.

24034—29——35

When one bears in mind the huge bulk of the animal, it is remarkable how noiselessly he moves through the jungle. During one of my excursions a small herd that had been browsing in a gully near Sigiriya passed quite close to my companion and myself. And if we had not known of their presence, we would never have suspected it from any sound of breaking twigs, overturned stones or other noises one might expect to be made by so large a beast passing through the dense forest.

This is not the place to discuss that ancient, world belief that the elephant "having no joints in his knees" can not lie down and, of course, always sleeps standing or while leaning against a tree or other support. Shakespeare echoes this age-old fallacy when he says that "the elephant hath joints, but none for courtesy; his legs are for necessity, not flexure." The fact is that an erect posture is generally comfortable for the great beast owing to the ponderous pillars of his body and he often dozes in the upright position, but that he can and does lie down is well known to observers. Sir Emerson Tennent long ago delivered the judgment of the court of scientific observation when he describes the real peculiarity of the great beast not only in lying down but in climbing up and down hill. He performs both acts easily and quickly, by extending his hind legs backwards as a man does when he kneels, instead of bringing them under him like the horse or any other quadruped.

> The wise purpose of this arrangement must be obvious to anyone who observes the struggle with which the horse gets up from the ground, and the violent efforts which he makes to raise himself erect. Such an exertion in the case of the elephant, and the force requisite to apply a similar movement to raise his weight (equal to 4 or 5 tons) would be attended with a dangerous strain upon the muscles, and hence the simple arrangement, which by enabling him to draw the hind feet gradually under him, assists him to rise almost without a perceptible effort.[4]

There may have been a period in the early history of Ceylon when the increase in herds of wild elephants created a menace to the crops of the native and possibly to the plantations of Europeans. At any rate, the government still permits so-called "sportsmen" to kill these gentle, useful, and now generally harmless animals. I was unable during my stay in the colony to obtain any facts justifying this practice except in the case of "rogues," about which I shall shortly say a word or two. No; the shooting of an elephant with a high-power rifle (through the head at a distance of a few yards) requires no special skill and is attended with no particular risk. The huntsman really gets as much glory out of it and risks his person about as much as he would by going out into a paddy field to fire at a bullock. The act is simply that of the man who is consciously or unconsciously satisfying his primitive

[4] Ceylon. An Account of the Island, etc. Fifth edition, London, Vol. II, p. 298.

lust for killing; it is a form of reversion to his original savagery. Lest I should be accused of using intemperate language, let me quote the words of Tennett, who wrote in 1860 what is still acknowledged to be the best account of Ceylon in general and of her natural history in particular:

> An ordinary traveler seldom comes upon elephants unless after sunset or toward daybreak, as they go to or return from their nightly visits to the tanks; but when by accident a herd is disturbed by day they evince, if unattacked, no disposition to become assailants; and if the attitude of defense which they instinctively assume prove sufficient to check the approach of the intruder, no further demonstration is to be apprehended. The shooting of elephants in Ceylon has been described with tiresome iteration in the successive journals of sporting gentlemen, but one who turns to their pages for traits of the animal and his instincts is disappointed to find little beyond graphic sketches of the daring and exploits of his pursuers, most of whom, having had no further opportunity of observation than is derived from a casual encounter with the outraged animal, have apparently tried to exalt their own prowess by misrepresenting the ordinary character of the elephant, describing him as "savage, wary, and revengeful." The shooting of an elephant, whatever endurance and adroitness the sport may display in other respects, requires the smallest possible skill as a marksman. Generally speaking, a single ball, planted in the forehead, ends the existence of the noble creature instantaneously; and expert sportsmen have been known to kill right and left, one with each barrel; but occasionally an elephant will not fall before several shots have been lodged in his head. To persons like myself, who are not addicted to what is called "sport," the statement of these wholesale slaughters is calculated to excite surprise and curiosity as to the nature of a passion that impels men to self-exposure and privation, in a pursuit which presents nothing but the monotonous recurrence of scenes of blood and suffering.

The taming of the wild elephant after his capture has been largely in the hands of a particular Singhalese caste for many centuries. The methods of taking and training these huge beasts is fairly well known and need not be discussed here. I have often talked over these matters with native hunters and keepers and find that preparing the wild animal for his various tasks and functions is a comparatively simple matter and to be successful must take the form of kindness and petting tempered by firmness, and never marred by cruelty. The chief employments of the tamed elephant are clearing forest lands, working in the brickyards, carrying and piling timber, stone, and other heavy objects, drawing wagons, cultivating the land and acting as ceremonial adjuncts to a temple or in the entourage of a nobleman.

The methods employed in taming a wild elephant extend over a period of several weeks or months; females are more docile and tractible than males and (as in the case of some human beings) there are some individuals that are naturally vicious, troublesome, and subject to fits of stubbornness and temper. The elephant's obedience to his mahout is due partly to fear but mostly to real affection, and many are the tales told to prove the claim that love rules his (or her)

mammoth heart. That kindness and common sense are the open sesame to an elephant's obedience is shown by the fact that, contrary to general belief, the animal's keeper may, in most instances, be changed frequently without interfering with the daily routine so long as he is treated with due consideration of his animal rights. These include that, above all, he must not be overworked, he must be regularly and properly fed (no small task) and must have two daily baths (with massage) as well as subsequent repose in a quiet, cool, and retired spot.

From all I could learn from reliable observers the lifetime of the average captive elephant, like that of the happily placed parrot, is about the span allotted to man—70 years.

Just as few persons have ever seen a dead mule so infrequently has the body of a dead elephant been found in the Singhalese forest. The natives believe that elephants bury their dead just like humans, and some assert that when an aged beast senses the approach of death he sets out for a remote and quiet valley and there patiently awaits his end. I know of a forest near Anaradhapura that conceals one of these reputed elephant cemeteries, but so well hidden is it that no man knows its exact location.

When an elephant has tusks he uses them and his trunk in most of his work. In lifting large rocks and timber a chain or rope is usually stretched around the object, which is also attached to a rope end. This latter the elephant holds in his mouth and with the aid of his trunk (and tusks when he has any) slowly carries the heavy burden to its allotted position, placing it with great care and evident appreciation of the purpose of his work. In all the operations the worker is ordered to carry on, he is the judge as to its safety and propriety. If he is to cross a bridge with or without a load or is commanded to essay a piece of cut stone or a heavy timber he considers the task and tests it with foot, trunk, and eye—taking all factors into consideration. If he thinks the ground unsafe or the weight of materials too great he hesitates or halts and if then urged to go ahead refuses, roars, and shows temper. He is captain of his own resources.

Writers on the subject devote much space to the "rogue" (Singhalese hora) elephant and he certainly is a pitiful and picturesque creature. He is nearly always a male who, an outcast from his herd owing to some breach of jungle law, is not allowed to join any other group and becomes a veritable Ishmaelite. He may drink, bathe, and eat in the vicinity of a herd but any attempt at familiarity or intimacy with any of its members is at once resented and the intruder is driven off, the process being punctuated by heavy blows with the trunk and butting with the head administered, it may be, by previous friends and companions. No wonder this otherwise gentle, intelligent, naturally gregarious and social animal becomes savage, morose,

and dangerous under such cavalier (and probably to him grossly unjust) treatment.

The outlaw turns bandit and murderer; he spends his nights in destroying plantations, overturning huts, and in pulling up rice plants, and young coconut palms. Hiding in the jungle by day these crazed beasts often prowl about unfrequented roads and jungle paths, and it is extremely dangerous for an unarmed man to wander in their neighborhood; and several instances of the killing of innocent natives by them have been described to me. Fortunately rogue elephants are rare in Ceylon and are said to number only about 1 in 500 in the wild state.

Of course, there is only one remedy for this anomaly—the death of the hora—and here, the sportsman may be said to be of some legitimate service. I clipped the following notice from the Ceylon Times of January 18, 1925:

> The government agent of the northwestern Province is prepared to issue licenses, free of stamp duty, for the destruction of two rogue elephants, the descriptions of which are appended below: 1. One near 24th milepost on Kurunegala-Puttalam road; male, height about 9 feet, white spots on head and trunk. 2. One near 26th milepost on Kurunegala-Puttalam road; male, height about 8 feet, shot wounds on left side and lower left jaw, appears to be lame on right front leg.

Of the carnivora found in the Ceylon jungle the bear (*Melursus ursinus*) is everywhere said to be the most dangerous, much more to be feared than the comparatively cowardly leopard. The Sinhalese animal has the usual ursine habits, but when frightened or if he imagines he is being pursued, never hesitates to attack anyone, native or European, that crosses his tracks. This species always attempts to claw and bite the head of its victim and I have seen frightful scars on the persons of survivors of these encounters. The wife of an English official, a noted huntress, whom I knew, was nearly killed by a bear despite the fact that she was armed with a rifle that she used with decided effect during the fight.

Although they are not very numerous or dangerous, one frequently hears about and occasionally sees (especially if he watches a water hole at night) the beautiful Ceylon leopard. This animal makes his home in the hill country, chiefly in the clefts of rocks and subsists on the wild deer and domestic animals found in and about the native villages. He is hunted and trapped for his fur which, by the way, is very poorly cured by the natives. Until they are full grown the baby leopard (brought in by native hunters) makes a pretty and amusing pet, which one may sometimes buy for a few rupees in the bazaars.

There are at least two distinct species of crocodiles in Ceylon, both with evil reputations. Although I have seen hundreds of these huge reptiles in Sinhalese waters and have heard many tales of misadven-

tures in which they were the assailants, I am inclined to believe that with ordinary precautions one may approach them without danger either from the shores of a tidal river or, more intimately, in a boat launched on any of their haunts in the larger tanks. In the estuaries of the low country one commonly finds the Indian crocodile (*Crocodilus porosus*). Some individuals of this species attain a length of 16 feet, or more. The full-grown Marsh crocodile (*C. palustris*) is rarely seen of greater length than 13 or 14 feet, and it is found almost exclusively in the fresh water tanks of the central and northern Provinces.

Although the Indian crocodile will undoubtedly attack human beings if driven by hunger, yet both species have learned to respect the man with the gun, and are likely to sink below water and swim silently away at his approach.

At Giant's Tank—an immense artificial lake or irrigation reservoir covering more than a hundred square miles and built five centuries ago by a Sinhalese king—I spent several days studying the aquatic and shore life of that marvelous construction. It was infested by thousands of crocodiles, most of them *C. palustris*, although I remarked some of the apparently larger examples of the Indian species that may have wandered in from the Gulf of Manaar close by. They lived on the waterfowl, tortoises, fish, etc., that abound in the waters of this great tank.

Constant warfare is waged on these saurians, partly because they form a good target for "sportsmen" (who rarely kill them by a single shot), partly for their skins, and to some extent because they are "vermin," preying on dogs and other domestic animals that bathe or swim in waters frequented by the reptiles. Hunters claim that fowl shot and falling into the water are likely to be seized and devoured by crocodiles.

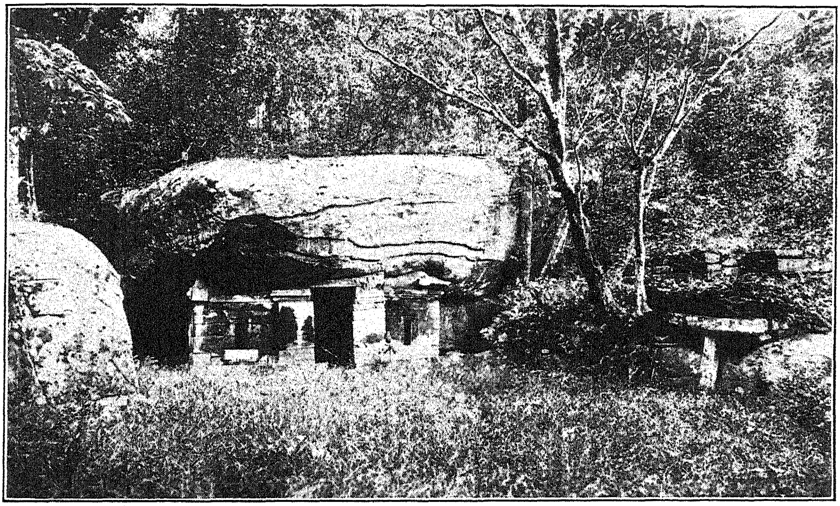
One day, while studying the biology of the lovely jungle about the Minneriya (or Minery) Tank—one of the largest artificial lakes in Ceylon—I was told by a first-hand observer that quite recently a planter, out shooting in a boat, lost a valuable retriever who with a duck in his mouth was seized, dragged beneath the waters of the lake, and never seen again.

In times of drought the smaller tanks often become dry, and then the Marsh crocodile leaves his usual dwelling and wanders over the country in search of water or mud, in which he may immerse himself until the coming of the rains. This fact explains the discovery of individual saurians sometimes miles away from the nearest water tank.

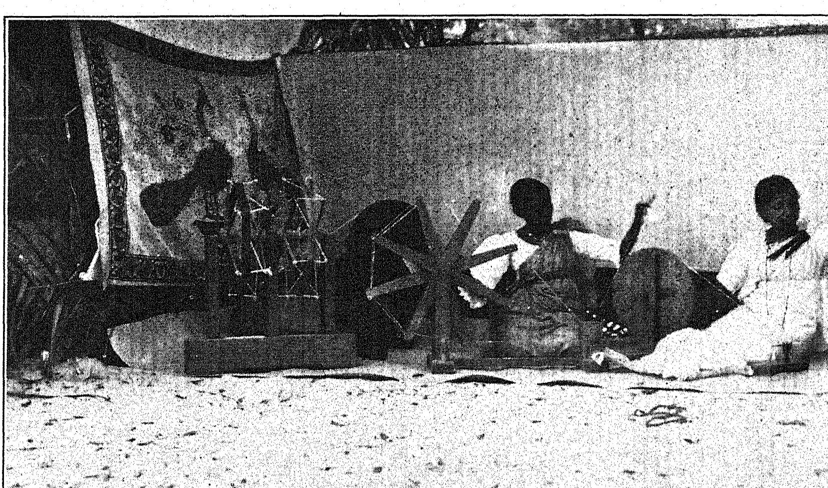
The larger tanks are the resort of many birds that are not exclusively aquatic. One of the most interesting of these is the Indian pied kingfisher. His activities may well occupy one's attention for

hours at a time. Unlike most other kingfishers he has no blue in his plumage but is a charming, spotted and barred mixture of black and white. This species avoids inland forest streams and prefers the lagoons and tanks near the coast. His diet is entire piscine, but he hunts his prey in a fashion quite unlike other members of his order. He does not dart into the water from the branch of a tree, stump, or telegraph pole like most kingfishers; he hovers in the air over the water as a kestrel poises over a meadow searching for field mice. In this suspended and hovering position above the lake he seems as fixed as if he were really resting on a stiff and dead branch of a tree. One sees him in this aerial perch turning his head from side to side, up and down, watching the waters beneath him. All at once his wings cease fluttering, he closes them tight about his body, and plunges straight as an arrow on his finny prey, which he rarely fails to grasp and carry ashore.

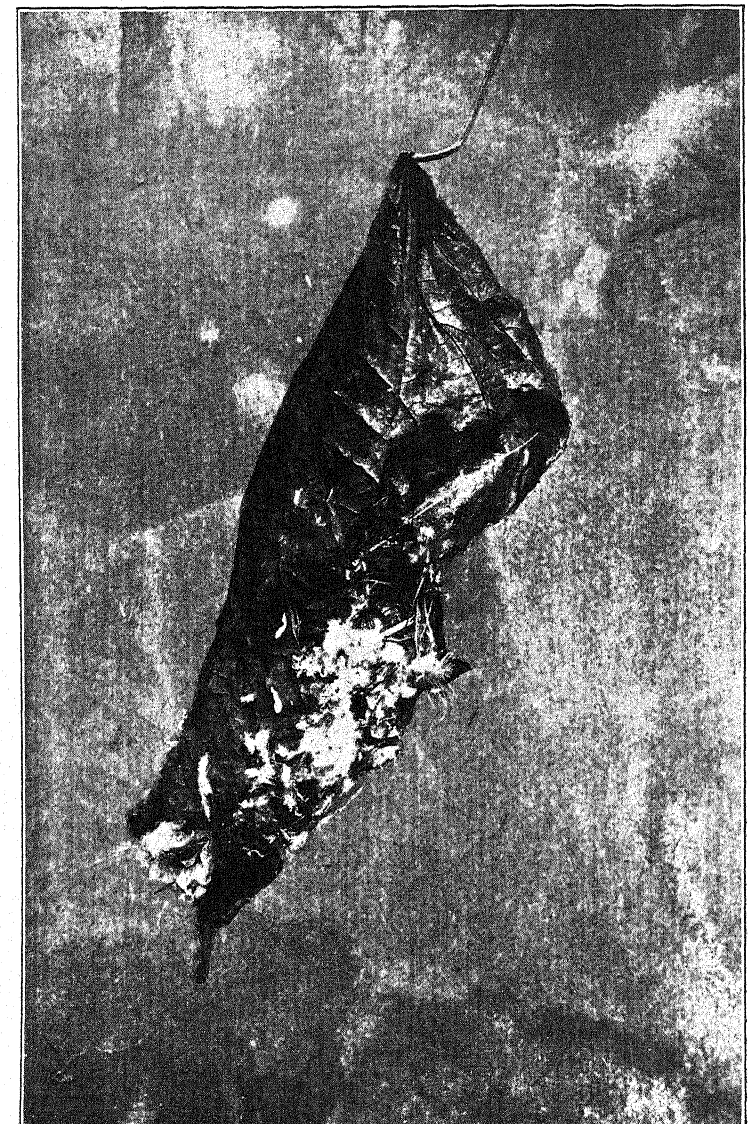
These are a few of the many wonderful sights that the Sinhalese forest offers to those that wander into her solitudes.



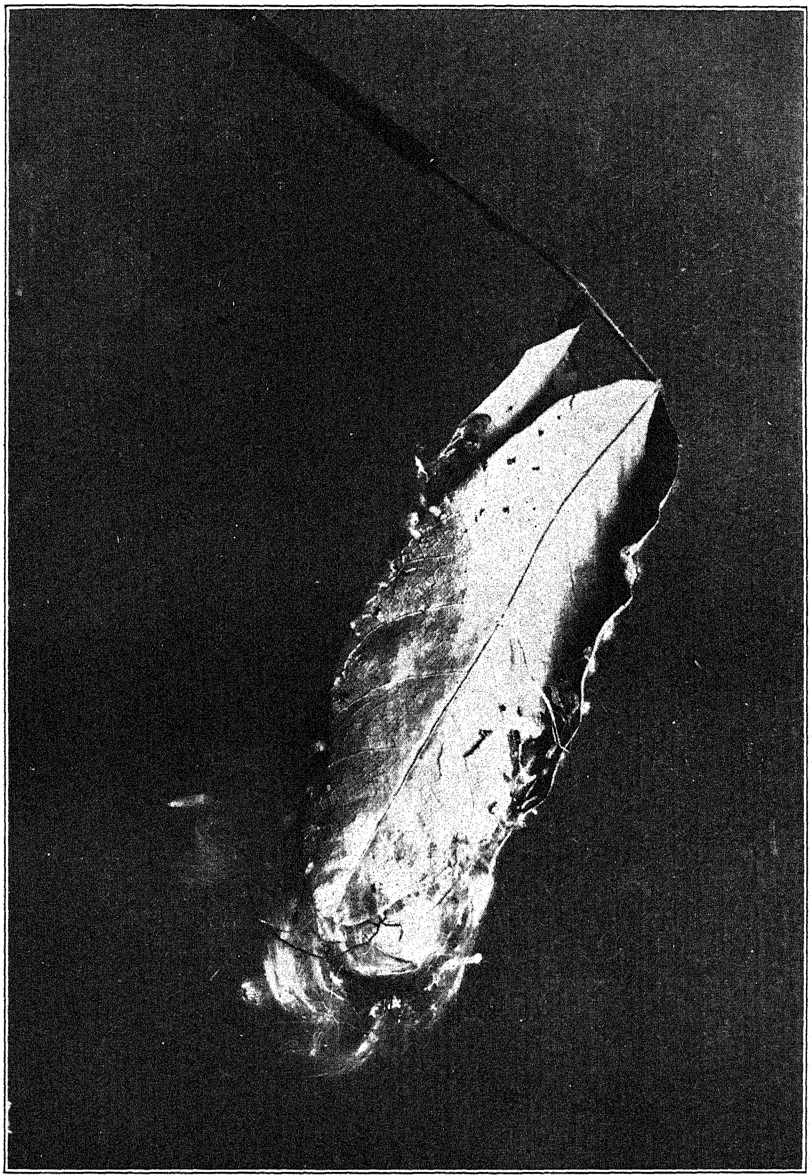
1. PART OF A DESERTED ROCK-BUILT PALACE IN THE JUNGLE OF ARAMKELLA, CEYLON



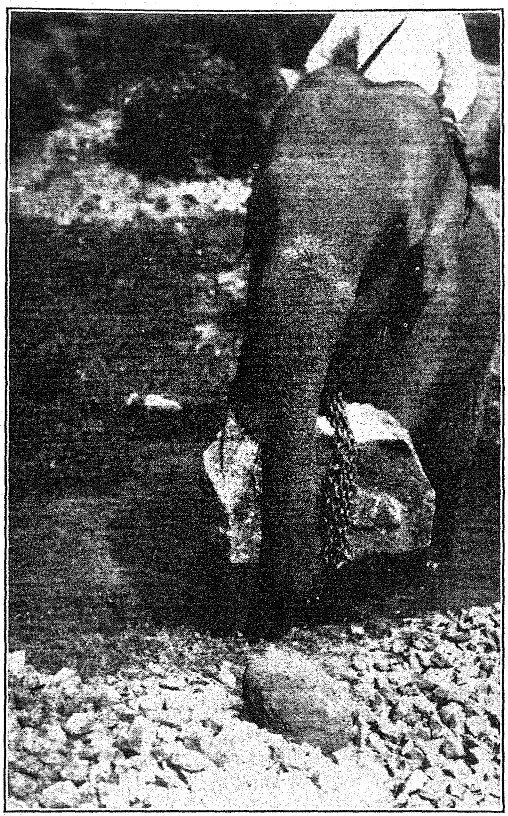
2. NATIVE WEAVERS AND SPINNERS, CEYLON



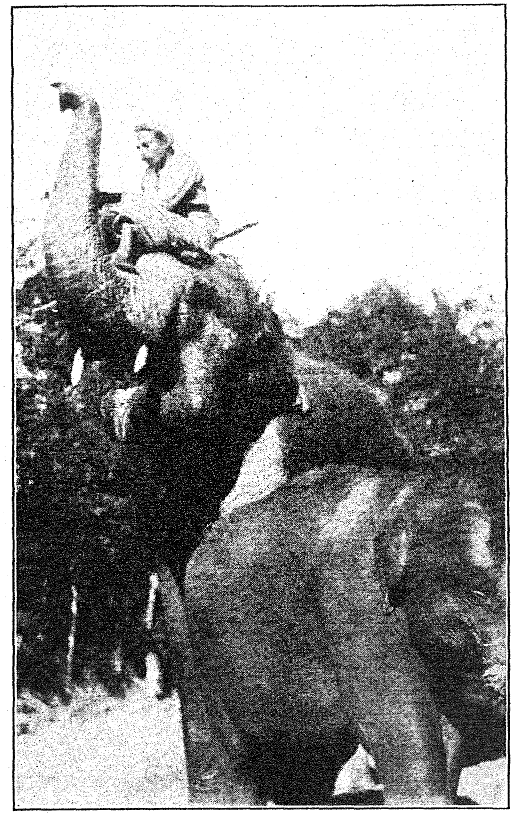
AN UNUSUAL TYPE OF TAILOR BIRD'S NEST FROM CEYLON



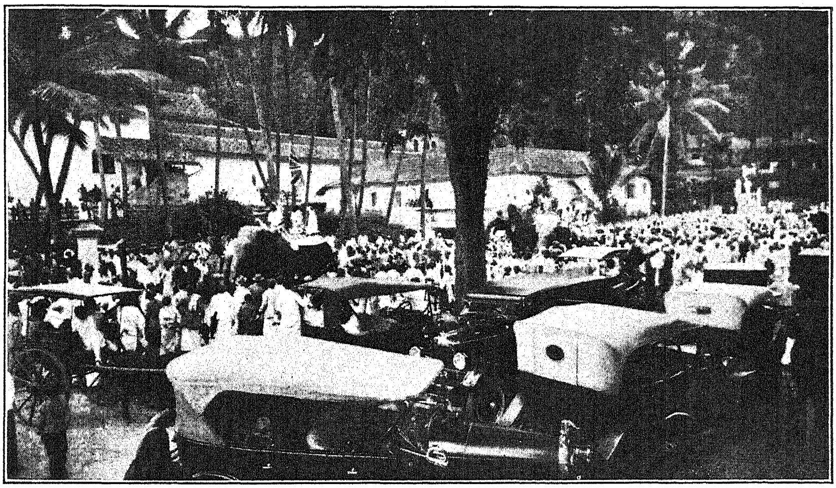
ONE FORM OF SEWING IN THE TAILOR BIRD'S NEST, CEYLON



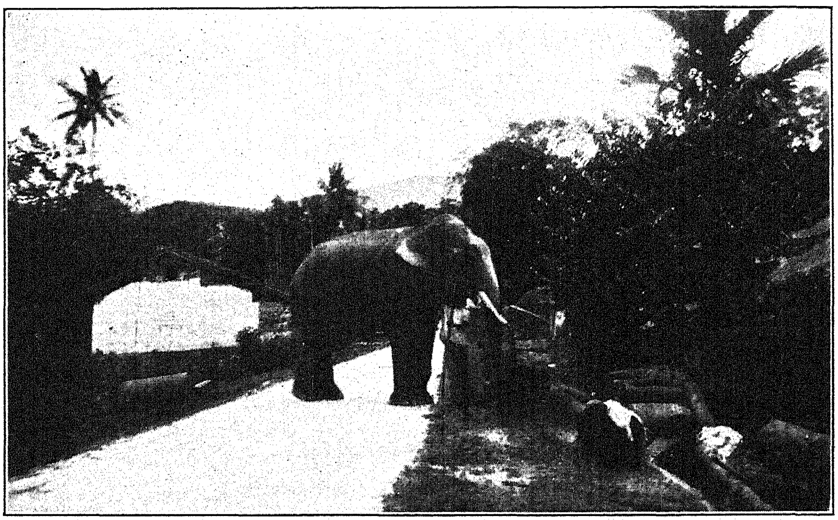
1. EARNING HIS DAILY BREAD ON CONSTRUCTION WORK IN CEYLON



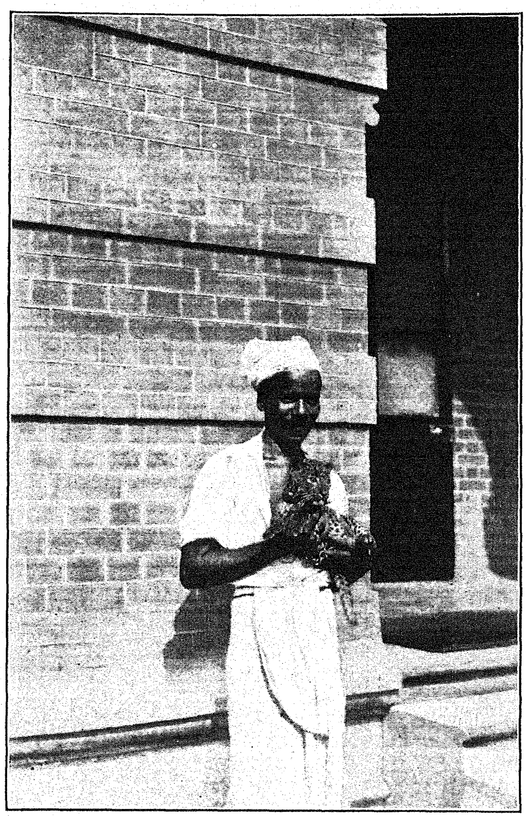
2. OBEYING THE WORD OF COMMAND. A WORKING ELEPHANT ON THE ROADSIDE, CEYLON



1. CEYLON ELEPHANTS TAKING PART IN A CEREMONIAL PROCESSION



2. RESTING FROM WORK ON A JUNGLE ROAD, CEYLON



1. THE DOCTOR'S PET AT THE COLOMBO HOSPITAL

2. FOREST DEVIL DANCERS IN CEYLON. THE MEDICINE MAN OF THE EAST

COMMUNICATION AMONG INSECTS

By N. E. McIndoo, Ph. D.

Senior Entomologist, Deciduous-Fruit Insect Investigations, Bureau of Entomology, United States Department of Agriculture

[With one plate]

INTRODUCTION

Communication among people implies some form of language. Regardless of whether it is an oral, a written, a sign, or a touch language, our definition of the word language is so well fixed in our minds that it can not be correctly used for any animal other than the human species. Nevertheless, the word, broadly speaking, means any form of communication and should not be confined solely to people. For fear of criticism recent writers on insect psychology have hardly dared to use the word language in connection with insect communication. However, in the writer's mind, communication among insects, particularly among the social ones, is better developed, and perhaps developed on a higher scale, than is communication among the most primitive tribes of people. Of course, these tribes are able to convey ideas by speech, gestures, signs, and to a limited degree by written characters; nevertheless, when we consider the minutest details of communication, the extremely acute senses of smell and touch in insects certainly surpass the crude and undeveloped means of these tribes of people. Then why do we confine the word language to people only? Merely because usage among ourselves has decreed this order, and we fail to consider that animals also must communicate, not only among their own species but more or less with other animals.

One of the unanswered questions concerning the lives of insects has been, how do they know one another, and how do they communicate information when once they have gained it? We are beginning to receive light on this subject, but have much yet to learn before we know all the details of the means which enable insects to live in communities. Ever since ancient times people have wondered how ants and bees, in particular, recognize their companions. Since it was not reasonable to suppose that each insect in a large community could recognize by sight every other individual in it, the

early entomologists imagined that insects must communicate by signs and passwords.

Kirby and Spence said that the social Hymenoptera (ants, bees, wasps, etc.) have means of communicating to each other information of various occurrences, and use a language which is mutually understood, and is not confined merely to conveying information of the presence or absence of danger, but is also coextensive with all their other occasions for communicating ideas to one another. Wonderful statement! These authors did not prove it, nor has anyone yet done so, although there may be some truth in it, for, to a limited extent, we do have exact knowledge which points in that direction.

Smell Plays the Most Important Part in Communication

So far as concerns the five special senses of sight, hearing, touch, smell, and taste, common to the higher animals, this discussion deals almost exclusively with the part played by smell. The other senses are alluded to here and there, but they are not discussed in detail because we have little or no exact knowledge as to the part played by them in communication.

1. HONEYBEES COMUNICATE LARGELY BY SMELL

Since communication among insects has been studied most seriously in connection with bees, most of our information on this subject pertains to them.

(A) ODORS IN A COLONY OF BEES SERVE AS A SMELL LANGUAGE

Von Buttel-Reepen first formulated the theory concerning the use of odors to explain how honeybees communicate. He said:

I believe that the following odors are present in a colony of bees:

1. The individual odor. It can be easily demonstrated that the queen odor varies with different individuals, and, on the same ground (germinal variation), an individual odor should be assigned to the workers.

2. All offspring of one mother (queen) have a common inherited family odor, in addition to the individual odors, belonging only to the progeny of one queen.

3. The brood and chyle odor.

4. The drone odor.

5. The wax odor. Since the wax is a glandular secretion, an exuded product, it may be safely taken for granted that, considered apart from the specific odor of wax, the individual odors of the wax generators adhere to the honeycomb. Accordingly the wax structures of different colonies have different odors.

6. The honey odor. That the honey of each colony (mixed with a secretion of the salivary glands) has its specific odor is readily seen from the old practice of beekeepers to which Bethe also alludes. If a queen be daubed with honey from a queenless colony, she will be accepted readily by that colony when inserted.

7. The hive odor (exhalation odor, colony odor). The hive odor is composed normally by a mixture of the preceding odors, or of some of them. Single bees, therefore, besides their individual odors, possess the family odor and especially the common, adhering hive odor, which forms the dominant factor in the various actions toward hive mates and strangers—that is, in mutual recognition between bees.

To support these views, Von Buttel-Reepen gave no proof other than his experiences as a practical beekeeper, which are far from being conclusive when we consider the scientific method; it will be shown, nevertheless, that his views are practically correct so far as they have been tested experimentally.

After becoming informed concerning the published results on this subject, the present writer in 1913 and 1914 undertook to verify experimentally the views of Von Buttel-Reepen. Such a difficult and complex undertaking he had never attempted before, although it seemed easy before starting, because the way apparently had already been mapped; all that remained to be done was to go to work. After many preliminary experiments, beset with all kinds of discouraging conditions, the problem proved not so easy as it had been imagined, and instead of becoming simplified it became deeper and more mysterious. What was to be done? Give up in despair? No; never! Such is not the way of a scientifically trained investigator. Well, then, what? After forgetting all his troubles he went at it again from a different point of view with a determination to win. By this time his own sense of smell had been "sharpened," or slightly educated to respond more readily to all the odors around him, so it was decided to start again by smelling the way.

It was thus determined that the human nose can be trained to recognize a number of characteristic bee odors. At the beginning of his tests the writer was able to distinguish the hive odor, the brood odor (the smell of the larvae and pupae, pl. 1, B, C, D), the honey (A) odor, the pollen or beebread (E) odor, the wax (J) odor, and the odor coming from the bee sting. After a few months' experience he was able to recognize the three castes of bees—queens, drones, and workers—merely by smelling them.

Old workers constantly give off the characteristic bee odor, and when seized they emit another distinct odor which comes from the poison ejected through the sting. No difference between the odor of a guard (pl. 1, I) and that of a fanner (G) could be distinguished; the odor from each closely resembles the hive odor; that is, the odor which comes out of a hive when the hive cover is removed. A worker carrying pollen gives off besides the bee odor another odor which comes from the pollen.

The younger the workers are the less pronounced is the bee odor emitted. To the human nose the odor emitted by nurse bees (pl. 1,

F) and wax generators (H) is much less pronounced than is the odor from old workers.

Workers just emerged from the cells have a faint, sweetish odor, but lack the characteristic bee odor, and workers removed from the cells just before they begin cutting their way out emit a still fainter sweetish odor.

Old queens have a strong, sweetish odor, while the odor from queens just emerged from their cells is much less pronounced. The queen odor is very pleasant, and is as characteristic of queens as is the bee odor of workers.

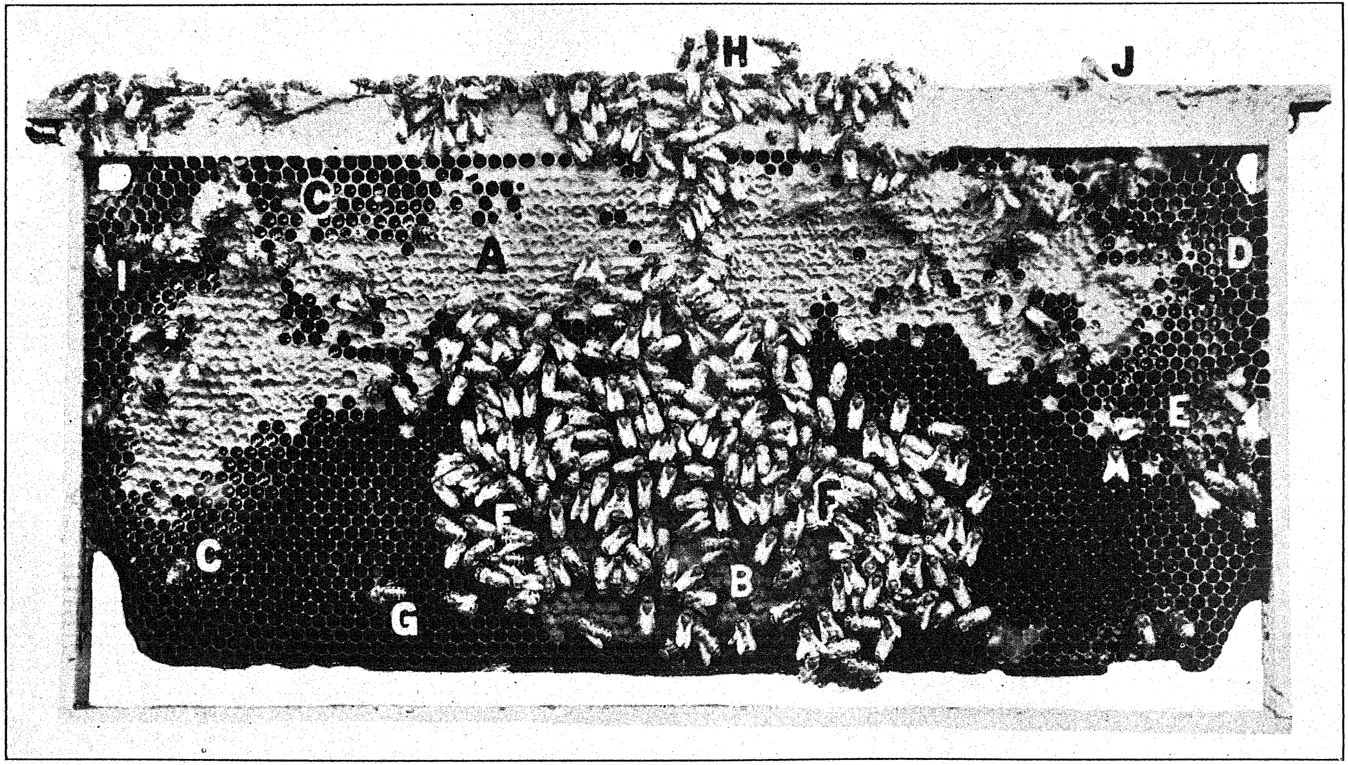
The majority of old drones have a faint odor, while every young drone has a stronger odor. This odor is slightly different from that of young workers and is less sweetish.

From statements that have been made it is evident that bees emit various odors, but if nothing more than the few observations mentioned could be recorded our story would end almost before it begins. We do not, however, have to build up our story on what we humans can detect with our poorly developed noses, because the activities of bees speak, as it were, a language, definite and infallible although foreign to us, which when correctly interpreted and recorded in our own language goes a long way to solve the mystery surrounding the communication between social insects.

By means of specially devised experiments the writer proved that the bees themselves can distinguish a much greater variety of smells than those heretofore enumerated, and that these play a most important part in their lives.

It is certain that a queen gives off an odor, and it seems reasonable to suppose that the odors from any two queens would be slightly different. All the offspring of the same queen seem to inherit a particular odor from her, called the family odor, which perhaps plays little or no part in the lives of bees, for it is certainly masked by the other odors. Drones seem to emit an odor peculiar to their sex, but little is definitely known about it. Apparently each worker emits an individual odor which is different from that of any other worker, and it is probable that the wax generators and nurse bees emit odors slightly different from those of the field bees.

Of all the odors produced by bees the hive odor is probably the most important. It seems to be the fundamental factor upon which the social life of a colony of bees depends, and perhaps upon which the social habit was acquired; without it a colony of bees could not exist. The hive odor is composed chiefly of the individaul odors from all the workers in a hive, and is supplemented by the odors from the queen, drones, combs, frames, walls of the hive, and still other sources. From this definition it is easily understood why no two colonies have the same hive odor. The hive odor of a queenless colony



PHOTOGRAPH OF A FRAME REMOVED FROM A HIVE OF BEES

A, sealed honey; B, sealed brood (pupæ); C, brood (eggs and young larvæ); D, old larvæ (cells ready to be sealed); E, pollen, or beebread; F, nurse bees; G, fanner; H, wax generators; I, guard; J, old wax. Much reduced in size

is perhaps considerably different from that of a colony which has a queen. The absence of a queen odor as a constituent of the hive odor probably explains why the workers in a queenless colony are irritable and never work normally. All the bees—workers, queen, and drones—in a colony carry the hive odor of that colony on their bodies, among the hairs. This odor serves as a sign, or mark, by which all the occupants of a hive know one another. Since the queen and drones are "aristocrats," they seem to disregard the sign that has been thrust upon them, but whenever a queen enters the wrong hive she is soon made to realize that she wears the wrong badge.

Worker bees returning to the hives from the field pass the guards unmolested, because they carry the proper sign, although the hive odor that they carry is fainter than when they left the hive, and it is partially masked by the odors from the nectar and pollen brought by them.

Bees kept in the open air for three days lose all the hive odor carried on their bodies, but each bee still emits its individual odor. When a colony is divided the hive odor in each half soon changes, so that by the end of the third day the original colony possesses a hive odor so different from that of the separated half of the colony that when workers from the two new colonies are placed together in observation cages they fight one another as though they had been separated all their lives.

Although a foreign hive odor calls forth the fighting spirit in workers, the queen odor under certain conditions seems pleasant to workers whether the queen belongs to their hive or to another hive. Even though the queen odor forms a part of the hive odor, it is probable that to the workers this odor stands out prominently from the hive odor. The fact that workers do not miss their queen for some time after she has left the hive indicates that her odor thoroughly pervades and qualifies the hive odor, and that whenever this constituent odor grows faint the workers "know" that she is not among them.

There has been much speculation concerning the ruling spirit or power in a colony of bees. The present writer is inclined to believe that a normal hive odor serves such a purpose. The hive odor is a means of preserving the social life of the bees from dangers without, and the queen odor which is a part of it insures continuation of the social life within. As already stated, the workers "know" their hive mates by the hive odor they carry. This odor insures harmony and a united defense when an enemy attacks the colony. The queen odor constantly informs the workers that their queen is present. Even though she does not rule, her presence means everything to the bees in perpetuating the colony. Thus, obeying the stimuli of the

hive odor and the queen odor, and following the guidance of instinct, a colony of bees perhaps could not want a better ruler.

Some of the foregoing statements are not conclusively proved, but as a whole they are probably not far from the truth. Here is one of the many openings in our scientific endeavors where a young, enthusiastic investigator, with the wisdom of a Solomon, can aid us wonderfully. Let him prove to us beyond a doubt that there are individual odors among bees, separate the individual odor from the hive odor and the family odor, analyze it in every way possible, and tell us all about its functions. "Very well," the young scientist will naturally say, but he will also doubtless come back asking, "How can it be separated from these other odors when it is already a part of them and is even their foundation"? That perplexing and seemingly baffling task we leave to the young scientist.

(B) VON FRISCH'S "LANGUAGE" OF BEES IS USED IN FOOD GETTING

(1) *The round dance is a means of communication for sugar-water collectors.*—Von Frisch, a professor of zoology in Germany, tells us that dancing among bees is almost as common as it is among people, and the same kinds of emotions are perhaps expressed in them as in us; that is, emotions of joy and gladness, with the body keyed up to the highest point of elation and overflowing with happiness. People dance to music, and the dance expresses little outside of an exalted state of happiness; bees, so far as we know, do not dance to music, but probably besides expressing high elation their dance has a life significance to them by informing the attending bees that food is near at hand and now is the time to secure it. And those who have closely studied the lives of bees know that they seem happiest when they are hard at work collecting their winter stores.

Further, we are informed that dancing among bees has been known for a long time, although no one hitherto has studied their dances sufficiently to interpret their meaning. At last Von Frisch believes that he has solved their mysteries in part if not entirely. As early as 1823 Unhoch wrote about bees dancing, but Unhoch's bee ballet was preceded by the observations of Spitzner in 1788, 35 years earlier.

When a scout bee has once found a supply of food, how does she communicate this information to her hive mates? The old theory, which until recently was pretty generally accepted by authorities on bees, was that the scout returned to her home, told the other bees about her wonderful discovery, and then led a party of them to the food. We are not told how the scout informed her hive mates; in fact, all the details are missing; the imagination is thus allowed to exert itself to various degrees, depending upon the ability of the

individual. Judging from Von Frisch's investigation, this theory is correct in that scouts do find food and do communicate this information to the other bees, but they do not lead a party of their hive mates to it. The most interesting part of Von Frisch's results concerns the method used by the scouts to inform other bees about the food which they have found.

In his preliminary experiments Von Frisch put sugar water in small dishes, which were placed in the open some distance from the observation hive. He then watched the scout bees when they came to the sugar water, then counted the bees visiting it after the scouts had found it. After being convinced that scouts caused other bees to come to the sugar water, he wondered how the scouts had informed their hive mates. He then watched the scouts in observation hives immediately upon their return from the sugar water, and invariably found that the successful scout rushed into the hive, gently crossed

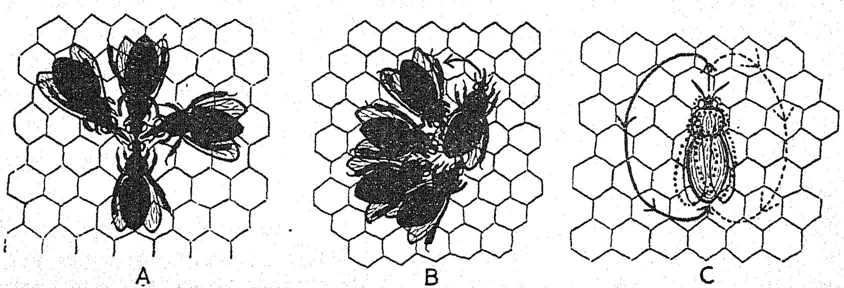


FIGURE 1.—Diagrams of worker bees on honeycomb. A, a sugar-water or nectar collector (lowermost bee) which has returned to the hive and is feeding three other bees; B, a nectar collector (the bee just below the arrow) followed by four attending bees, performing the round dance; C, the movements made by a pollen collector while performing the tail-wagging dance. (After von Frisch)

her palpitating antennae with those of other workers coming in contact with her, and immediately began sharing her sugar water with the other bees (fig. 1, A). By the time she had reached the thickest group of bees on the comb, she began the peculiar circular, or round, dance, which will be described in detail under the following heading.

After repeating these experiments many times, Von Frisch convinced himself that the scout bees which first found the dish of sugar water did not accompany the other bees to it; he observed that before a scout had disappeared among the bees in the hive the other collectors had rushed from the hive; by actually timing them he determined that nearly all of them had appeared at the same dish five minutes after coming in contact with the scout. Furthermore, while watching scouts passing from their dancing spots to the hive entrance and from there to the food supply he never observed other would-be collectors following them.

At this stage of his investigation he wonders what sense brought about the communication. He eliminates sight for two reasons; first, because usually there is no light inside a hive; and secondly, because in the lighted observation hives he noticed that the light did not seem to have any effect either on the dancing bee or on the ones attending her. He also eliminates hearing, chiefly because that sense is not well established in bees. He says that the sense of taste can play a rôle only while the dancer is feeding the other bees. Von Frisch favors the double means of communication through the senses of touch and smell set forth in the contact-odor theory of Forel, because he believes that organs of both touch and smell are present in the antennae, that when the antennae were crossed the dancer conveyed to the attending bees part of the information to be communicated, and that at the same time the mouth parts of the dancer certainly bore so much of the sugar water that it could have been perceived by the attending bees. Von Frisch believes that the round dance itself is a means of communication, but not the only means of telling the attending bees that there is food outside the hive; that it is not absolutely necessary, but is a helpful factor. It is conclusively shown, he says, that in a normal hive of bees a definite region of it is preferred by the collectors as an abode, thereby easily facilitating the communication to them of whatever information is to be imparted.

(2) *The round dance is a means of communication for collectors of nectar.*—The experiments just described were repeated on a much larger scale and greatly expanded in kind by using the nectar secreted by plants, and by watching bees collecting honey which had been served purposely for them. It was determined that bees that are collecting nectar and honey return to the hives, share their food with the attending bees, and perform the round dance in the same manner as do the collectors of sugar water.

Using a nectar collector as an example, and beginning with the act of collecting nectar, the complete performance, including the round dance as described and figured by Von Frisch, is about as follows: A certain plant opens its blossoms, spreads its fragrance far and wide, and announces to the insect world that it is ready to be cross-pollinated. Along comes a scout bee, attracted either by sight or by smell, or possibly by both; the bee finds the blossoms overflowing with rich and fragrant nectar. She is happy and works hard to fill her honey stomach with the precious liquid, and at the same time impregnates her body with the odor from the flowers visited. Now she flies high into the air and takes a bee line home, where she passes immediately into her hive, eager to announce her wonderful discovery to the other nectar collectors. Evidently knowing just where to find them in the hive, she rushes among them and salutes them with her extended, palpitating antennae, which gently

cross and recross those of the other bees; while she is doing this kind of handshaking she is also sharing her nectar with several of the attending bees (fig. 1, A). By the time she reaches the thickest group of the attending bees, perhaps "thinking" that she has not yet attracted enough attention, she dances around on the comb in narrow semicircles, first in one direction, then in the other, keeping up the dance for a quarter or a half minute, but rarely for a whole minute. While quickly passing through these semicircles the dancing bee comes in direct contact with the attending bees; these are greatly excited, and a few of them follow behind the dancer with their antennae touching her abdomen (fig. 1, B). In this brief period, in almost total darkness, and perhaps with no means other than the extremely acute senses of touch and smell, the attending bees seem to acquire without difficulty the necessary information about the nectar to be sought. We can not even guess what the dancer tells the attending bees while stroking their antennae; neither can we imagine what kind of an impression is produced in the little "minds" of the attending bees by the fragrant odor of the flower, carried on the body of the dancer. At any rate, Von Frisch would have us believe that they associate this odor with the plant which secretes the nectar to be sought. All we definitely know is that the bees become greatly excited by attending the round dance, quickly rush out of the hive, and search in all directions for the plants furnishing this particular nectar. This action may help to explain why bees have the habit of collecting nectar or pollen from only one kind of plant on any one trip.

We have now described the action of a single round dancer, in the course of which we have found that the bees attending her went in search of food, but how do these other nectar collectors act upon their return to the hive? And how do they inform one another about the abundance or scarcity of the food sought?

Von Frisch seems to infer that this is an easy question when once we understand the meaning of the round dance. Each collector that finds a supply of nectar of the particular plant sought, returns home and performs her own particular round dance, and of course each dancer will have her own group of attending bees. In turn, these several groups of excited bees rush out of the hive in search of the desired food. As long as the supply of nectar is abundant, furnishing work for every collector available, the number of collectors increases up to the maximum when the supply seems the greatest; but as soon as the bees realize that the supply is being exhausted the number of collectors is gradually decreased. The decrease is accomplished in two ways; the returning collectors cease their dancing, thereby ceasing to incite to activity other field bees not yet

excited by the dance, and they gradually quit going after nectar. This behavior of bees reminds the writer of the behavior of people performing a piece of work. As long as there is an abundance of enthusiasm and work to be done everything goes well; but as soon as the enthusiasm lags and the end of the work is in sight the organization weakens and becomes filled with quitters. The many experiments which he conducted caused Von Frisch to conclude that only the odor which adheres to the dancer informs the other bees about the location of the food to be sought, while the dance itself indicates to them that there is work to be done.

(3) *Tail-wagging dance is means of communication for pollen collectors.*—Von Frisch informs us that the tail-wagging dance of the pollen collectors is well known among beekeepers, and many times has been described in the bee journals, with many interpretations. From his own observations he explains it as a means of announcing to the bees in the hive the existence of a pollen source out of doors. The odor of the pollen, carried by a scout collector, tells the other collectors the kind of flower or flowers furnishing it, and by scouting at large over the surrounding fields the other collectors are then able to find it for themselves.

Successful scout pollen collectors, heavily laden with pollen, or beebread, as some of the beekeepers call it, return from the fields to their homes, where they may be seen to enter the hive; thereafter they must be watched in an observation hive if one wants to see them perform this particular dance, characteristically described by Von Frisch as the tail-wagging dance, to distinguish it from the round dance of the nectar collectors. The most striking feature of the round dance is the rapid revolving or turning of the performer's abdomen while small semicircles are being described, whereas the most characteristic part of the tail-wagging dance is the wagging or swaying of the abdomen while the bee runs forward quickly in a straight line. In a typical case a pollen collector, laden with pollen, comes home, crawls upward on the comb, and when in the midst of other bees begins to attract the attention of her associates by performing this peculiar dance. The dancer first describes a semicircle either to the right or left on the comb (fig. 1, C), then runs forward in a straight line over two or three cells to the starting point, from which she describes another semicircle in the opposite direction, thus completing an entire circuit. The performer again returns along the diameter of the circle to the original starting point, and thereafter repeatedly goes through the same maneuver, alternating semicircles on one side or the other with straightforward runs. The running in semicircles is done quietly, without any striking movement, but each time the dancer makes the straightforward run she wags her tail from 4 to 12 times. These waggings consist of very quick, rhyth-

mical, sidewise movements of the entire body, but the swaying is greatest at the tip of the abdomen and least at the head (fig. 1, C, dotted line around abdomen). Scarcely has the dance begun when other bees crowd closely behind the performer, and when the dance is finished many of the attending bees have disappeared and gone out of the hive in search of the particular pollen carried by the dancer.

Von Frisch concludes that merely by smell bees can readily distinguish between the various pollen dusts carried by the collectors, and that when they have once taken a good smell of a certain pollen they remember the odor while hunting until its source has been found in the field.

(4) *Body odors of bees aid in collecting food.*—Von Frisch and Rösch hold that bees must hunt at large for the desired food after having once smelled it on the scouts. While visiting flowers collectors of both nectar and pollen impregnate the immediate neighborhood with their body odors, thus making it less difficult for other collectors to find those particular flowers.

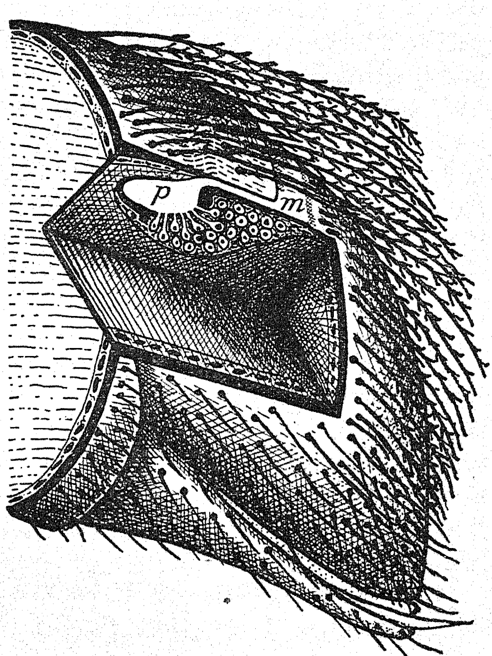


FIGURE 2.—Diagrammatic transverse-longitudinal view of end of abdomen of a worker bee, showing scent-producing organ, composed of articular membrane (m), canal or pouch (p), and numerous gland cells lying beneath this pouch

Other observers have remarked that bees, while visiting flowers, do not expose their scent organs. (Fig. 2.) Von Frisch and Rösch say that this is true only under certain conditions. For example, these writers saw nectar collectors visiting a certain flower without at the time exposing the scent organs. Upon plucking and examining the flowers they found that no nectar was being secreted; the bees did not mislead other bees by scenting the air near the nectarless flowers. Later, however, the same species of flower was visited by nectar collectors which were exposing their scent organs; an examination proved that the flowers were secreting nectar. Pollen collectors were next observed, and similar results were obtained as to their behavior while collecting.

The next question to be decided was, Does the odor from the scent organs allure the collectors from all the hives or from only one

hive? After experimenting with two observation hives of bees, a small hive and a large one, it was decided that the odor from the scent organs serves to indicate where an abundant supply of nectar or pollen may be had, and that the odor impregnating this particular spot also serves as a specific lure to bees from the same hive, but that it is noticed little or not at all by collectors from a different hive.

Another question to be decided was, Does the round dance excite only nectar collectors and does the tail-wagging dance excite only pollen collectors? If the answer is affirmative in either case, which is the more important factor, the form of the dance or the odor of the food carried? It was concluded that under natural conditions these dances are two characteristics of bee "language," in that only nectar collectors respond to the round dance and only pollen collectors to the tail-wagging dance, but the odor of the food carried proved to be the more important factor involved.

2. ANTS COMMUNICATE LARGELY BY SMELL

It has been shown how bees communicate among themselves by smell. This method of communication might be called a smell language, to distinguish it from other methods which in honeybees are certainly secondary. It will be shown that ants also have a smell language, although less is known about it than about the smell language of bees. Before discussing the part played by smell, let us first consider the other possible methods of communication between ants.

(A) BEHAVIOR OF ANTS SUGGESTS MEANS OF COMMUNICATION

Ever since ancient times observers of ants have been impressed with the idea that these little colonial creatures must have a language, yet even to this day we know but little about this language. The idea that ants must have some definite means of communication is to be found in various passages of ancient writers, even from the days of Solomon down to Aristotle and the early Romans; yes, even down to the time of the Italian poet Dante. Otherwise, how could the ant be such a wise creature? We recall what Solomon in all his wisdom and glory said about the little ant:

> Go to the ant, thou sluggard; consider her ways, and be wise; which having no guide, overseer, or ruler, provideth her meat in the summer, and gathereth her food in the harvest.

Most authorities on ants have little to say about communication, but nevertheless firmly believe that ants have means of conveying information to one another. When we recall that many ants are totally blind we can not consider sight the chief factor in communication; the blind individuals apparently live and prosper just as well as those having highly developed eyes. Some writers imagine that

hearing aids in communication, but as we have no definite knowledge that ants hear, at least as we humans hear, we can not consider hearing the chief factor; ants, however, can make sounds by stridulating; in other words, by rubbing certain parts of their body against other parts. When ants are in actual contact with one another their acute sense of touch is certainly an important factor in communication, but ants can easily distinguish each other before they come in contact; it is highly probable, therefore, that touch is second in importance to smell. Ants, furthermore, have the habit of making various kinds of signs and gestures, which most writers believe aid them in conveying information. Many of their gestures, such as particular movements of the antennae, jaws, head, and abdomen, have been interpreted as signs which may be understood and acted on by other ants. Wasmann has compiled a kind of dictionary, based on a number of different antennal strokes, each supposedly having its own meaning. The meaning depends chiefly on the nature of the stroke, whether quick or slow, heavy or light, at longer or shorter intervals, on the top or side of the head, or only on the antennae, and in still other ways.

Huber was a firm believer in an antennal language, which is to be classified mostly, if not entirely, as a touch language. He tells about some ants which he had held as captives four months, during which they had not communicated with their former companions in the nest. One day some of these captives accidently escaped; they were found and recognized by their former mates, who caressed them with their antennae, took them up by the jaws, and led them back to the nest. The ants in the nest presently went in a crowd to seek the remaining captives, and after some time had returned all of them to their old home.

In the case of both ants and bees the utmost harmony reigns between those belonging to the same community, whereas all others are enemies. It is particularly true, remarks Lubbock, that ants "know" all their comrades, even after a long separation. If a strange ant is put among ants of another nest she is at once attacked. This implies that all ants or all bees of a community have the power of recognizing one another; a most surprising fact when we consider the shortness of their lives and the immense numbers in a single community. Lubbock returned some ants to their old nest after a separation of a year and nine months, yet they were amicably received and evidently recognized as friends. He finally concluded that ants recognize their friends even when intoxicated, and know the young born in their own nest, even when the young have been taken out of the cocoons by strangers. These facts indicate strongly that recognition is not effected by means of signs and passwords, but by odors.

(B) ODORS PLAY AN IMPORTANT PART IN COMMUNICATION

Wheeler remarks that it is generally admitted that the segregation of colonies of ants is caused by the presence of characteristic odors which vary with the species, colony, and caste, and which, according to Fielde, vary also with the developmental stages of the individual ant. Of course, the human nose can not detect all of these odors, although Wheeler further says that even the degenerate human nose can detect the different species of ants by their odors, and in some cases even the different castes, but that the ants themselves carry the discrimination much further. He believes that ants have not only extremely acute powers of discriminating odors, but no less extraordinary powers of associating them. He states that the human nose can readily detect the pungent and ether odor of *Formica rufa;* another species of ant has a smoky smell; another smells like lemon geranium or oil of citronella; another strongly like mammalian excrement; another less strongly so; and another like rotten coconuts.

Fielde claims that a certain species of ant bears three distinct odors; (1) A scent deposited by her feet, forming an individual trail, whereby she traces her own steps; (2) an inherent and inherited odor, manifested over her whole body, identical in quality for queens and workers of the same lineage, and an instrument for the recognition of blood relations; and (3) a nest odor, consisting of the commingled odors of all the members of the colony, used to distinguish their nest from the nests of aliens. Miss Fielde says that the odor of ants changes with their age, and that "a cause of feud between ants of the same species living in different communities is a difference of odor arising out of difference of age in the queens whose progeny constitute the communities, and difference of age in the ants composing the community." She calls this odor the progressive odor, and further claims that fear and hostility are excited in the ant by an odor which has not been encountered and found to be compatible with the comfort of the ant. The same author calls the family or inherent odor the specific odor which is transmitted by the mother ant to all her offspring of both sexes within the species. Miss Fielde claims that ants not only differentiate the innate odors peculiar to the species, sex, caste, and individual, but also the incurred odor of the nest and environment; furthermore, that they can detect the progressive change of odors due to change of physiological condition with the changing age of the individual. She says that "as worker ants advance in age their progressive odor intensifies or changes to such a degree that they may be said to attain a new odor every two or three months."

Judging from the experiments on ants made by various observers, the family odor in these insects seems to play an important rôle by

enabling the offspring of one queen to distinguish members of their family from those of alien families. To ants the family odor is probably as important as is the nest odor, but among honeybees, where certain social habits have been advanced to a higher degree, the family odor is of little or no use, because the hive odor has assumed such an important rôle in the recognition of the members of the same or of a different colony. Each colony of bees has its own hive odor, a small share of which adheres to the body of each member of that colony, so that a bee is never entirely devoid of the hive odor. Should workers be forced to remain in the open air for at least three days, which is scarcely possible, they would lose their hive odor, and should they then try to enter their own hive they would be attacked by their sister guards because the family odor emitted by them would not be a sufficient proof that they were friends; if the guards had also lost their hive odor they would of course let these sisters enter unmolested.

3. TERMITES, OR WHITE ANTS, COMMUNICATE LARGELY BY SMELL

Since the social life of termites is in many respects so similar to that of ants, we should expect their means of communication to be similar, but from the little we know about these means there are some differences. Since blindness prevails more in termites than in ants, we can not consider sight as playing an equally important rôle, but smell and touch are probably as important in termites as in ants. Termites make a peculiar convulsive or jerky movement which is believed to be a method of communication. Snyder says that they communicate by rapping their heads against objects, producing sounds audible to the human ear in some cases, but not in others.

Banks and Snyder say that our common termites go through an amatory procedure, or a kind of courtship, immediately before and after the loss of the wings preliminary to mating. The male follows the female tirelessly and persistently, with his head close to her abdomen, and often touching her with his antennae. The sexual attraction seems to be caused by a secretion at the end of the abdomen.

No one has made a special study of the odors emitted by termites, although all the writers on this subject are satisfied that these colonial insects have nest or colony odors, from which it may be concluded that there are also family odors and individual odors. When one or more termites are removed from a community and returned after hours or days of isolation they are received back into the community without disturbance, but usually a termite from another colony is at once set upon and killed. In the first instance the family odor probably protected the termite; in the second, the insect had neither the proper family odor nor the friendly nest odor.

4. MEANS OF PRODUCING ODORS FOR RECOGNITION

Long ago it was stated that most animals emit odors peculiar not only to the individual, variety, race, and species, but also to the genus, family, order, and class, and that these odors are the chief means by which one animal recognizes other animals. Without the aid of the eyes the degenerate human nose is able to distinguish a horse from a cow, a goat from a roe, a dog from a cat, a martin from a fox, a crow from a pigeon, a parrot from a hen, a lizard from a snake, and even a carrion crow from a hooded crow.

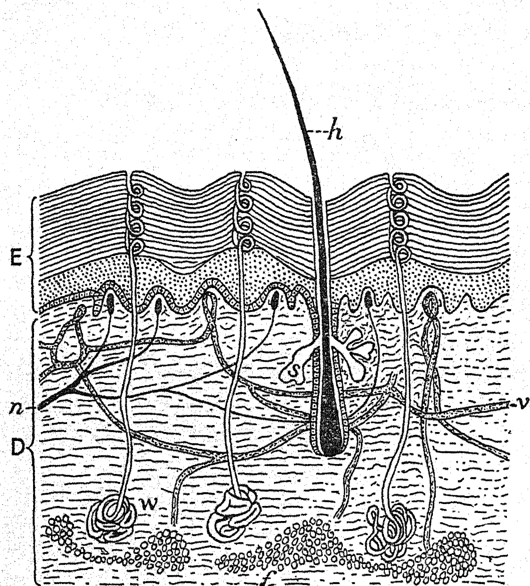


FIGURE 3.—Diagram of a section of human skin showing epidermis (E); dermis (D); hair (*h*), arising from a hair follicle into which empties the secretion of oil or sebaceous glands (*s*); sweat glands (*w*) and their ducts, which pass in a spiral through the epidermis; blood vessels (*v*); fat cell (*f*), and nerve (*n*), which innervates the sense papillæ. (From Hertwig, after Wiedersheim, slightly modified)

All odors arising from the skin, hair, feathers, or scales of an animal have their sources in secretions or excretions which pass through the skin or integument by special ducts or pores, and not directly by osmosis; in some animals, however, particularly in certain insects, the existence of these pores has not yet been definitely established. The scent-producing organs, which may possibly include three types of glands—special scent glands, sweat glands, and subaceous glands—have not yet been thoroughly and systematically studied in any order of animals, and in most cases definite and specific functions have not been assigned to the various types. Odors may also be emitted from the body at either end of the ailmentary canal, but these probably play no part in recognition among animals.

Special scent glands have been found in a large number of animals, including numerous insects. They are located in various parts of the anatomy. Some lie in the feet; the secondary function of these is probably to leave scented tracks wherever the animal steps.

The skin of mammals in particular is characterized by richness in glands, of which there are two kinds; sweat glands (fig. 3, *w*),

which are common to mammals, and sebaceous or oil glands (*s*), common to birds and mammals. The sebaceous glands usually open around the base of hairs (*h*) in depressions called hair follicles, and not into the cavity or lumen of the hairs. On the palms of a human being sweat glands number 1,100 to the square centimeter, and their total number in man is said to be about two million.

It is the primary function of the sebaceous glands to lubricate the skin, hair, and feathers of animals; if they have a secondary function it may be that of recognition. When fresh, the secretion of these glands, called sebum, is an oily semifluid, but on the surface of the skin it solidifies, forming a greasy coating.

Primarily, the sweat glands constitute an automatic device for keeping the body temperature constant, while their secondary function is probably *recognition*. The perspiration is a clear, colorless fluid with a salty taste, and characterized by different odors from different parts of the body. In composition it is 99 per cent water, the remaining 1 per cent consisting of urea, ammonia, fatty substances, and certain other compounds. Its neutral fats are said to come from the sebaceous glands, although the sweat glands themselves secrete other fatty substances of which the volatile fatty acids emit the peculiar odor characteristic of sweat.

We can now understand why the odors emitted from two animals differ. We can also understand how dogs, by smell alone, even in total darkness, can distinguish their masters and the members of their respective households from strangers. Besides the glands already mentioned, animals have certain other glands whose secretions may also be odorous and perhaps sexually attractive; for instance, the glands connected with the genitals.

Sweat glands and sebaceous glands are present in the higher animals but not in insects; therefore insects, so far as we know, do not sweat. They belong to the cold-blooded animals, whose temperature most of the time corresponds more or less closely to the temperature of the air in which they live, and therefore do not need sweat glands. Many insects, however, possess glands which are widely distributed over the entire surface of the body and closely resemble sebaceous glands. Since these glands are not needed for purposes of lubrication they must have some other function, and it seems very reasonable to suppose that they are used for recognition. Those of the cotton boll weevil (fig. 4, A, *p*) illustrate this point.

Among specialized glands of this type are the adhesive-secreting glands (fig. 4, B) in the feet of many insects, particularly of all those that can walk on perpendicular surfaces or even upside down. Although the primary function of these glands is certainly to enable insects to walk on smooth, perpendicular surfaces, a secondary use is probably that of recognition. In ants, termites, and all the other

insects which follow scented trails this secondary use seems especially probable. The adhesive-secreting glands lie in the soft pads on the underside of the feet, and are usually connected with small hairs, called tenent hairs (*h*). These hairs are hollow and are usually open at their tips; through them the sticky secretion from the glands is forced to the exterior, where under certain conditions it may be seen as fine threads. This example shows how scented trails may possibly be made by the feet of insects in much the same way as scented tracks are made by dogs, the sweat glands in the pads of the dogs' feet seeming to deposit an odorous material wherever a dog steps. Ants and termites have been observed to lay down scented trails by depositing tiny specks of material from the tip ends of their abdomens, and thereafter they follow these tracks.

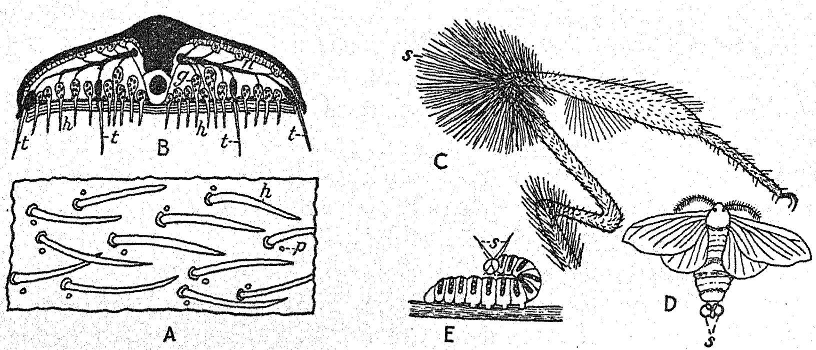


FIGURE 4.—Diagrams showing locations of scent glands of insects. A, superficial view of a portion of an elytron or wing cover of a cotton boll weevil, showing large hairs (*h*) and widely scattered gland pores (*p*). B, cross section through tarsus or foot of a beetle, showing nerves (*n*) running to touch hairs (*t*) and gland cells (*g*) which, when stimulated, force their sticky secretion through openings in numerous hairs (*h*) on the "soles" of the feet. (From Packard, after Dewitz.) C, front leg of a male moth, showing the fan-shaped group of scent hairs (*s*). (From Schröder, after Illig.) D, female of the silkworm moth, showing the eversible sacs (*s*) as scent-producing organs. (From Schröder, after Freiling.) E, larva of a swallow-tail butterfly, showing eversible sacs or osmaterium (*s*), which emit a defensive odor. (After Berlese)

Scent glands of a second type include peculiarly arranged tufts of long hairs, on the legs and elsewhere, on male moths (fig. 4, C, *s*). The secretions from all these organs have been credited with purposes of allurement and are supposed to attract the opposite sex. They have been regarded as aromatic, volatile oils. Their odors usually are to man very agreeable indeed, and have been described as resembling many of our most pleasing scents, even including those from some of our fancy perfumes. As a rule, each species of insect has its own characteristic odor.

In the case of a third type of scent glands, eversible sacs or pouches, usually lined with tiny hairs which connect with the glands, serve as special devices for storing the secretion and distributing the odors. With some species the odors from these glands serve

for allurement (fig. 4, D, *s*), and in the case of other species for defense (fig. 4, E, *s*).

The dorsal scent gland of the honeybee (fig. 2, p. 551) belongs to a fourth type and is one of the most highly developed of the scent glands used for purposes of recognition.

5. ANTS RIVAL DOGS IN TRACING TRACKS

For ages the dog's nose has been considered the most acute smelling organ among all animals, but a review of the literature shows that the "noses" of insects are close competitors and possibly second to none. It is well known that dogs can trace the tracks of man and animals merely by smell, as was recently demonstrated by Buytendijk, a Dutch physiologist. During the World War a lively interest was taken in the breeding and training of police dogs. Those used were such reliable trackers that they were known to find the scent under snow when bloodhounds were useless, and they rendered great aid in bringing in the wounded.

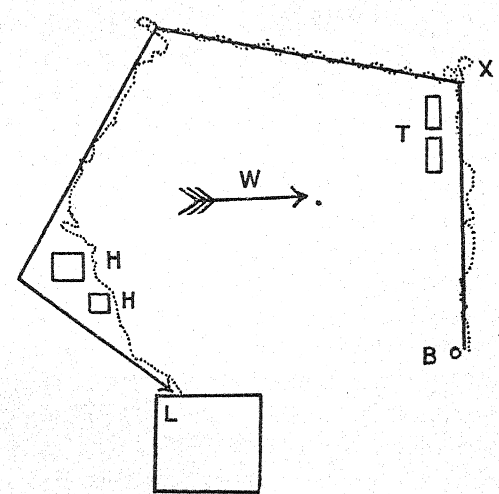


FIGURE 5.—Diagram illustrating experiment to test the ability of a police dog to follow the trail of a human being. (After Buytendijk)

On a level, sandy place in Amsterdam a boy followed the route indicated by the solid line in Figure 5, beginning at a tree B, and ending at a laboratory L. A strong wind was blowing in the direction indicated by the arrow W. At T were two street cars, and at H two huts used by construction workers. As soon as the boy had finished the trip a police dog was led to the tree, allowed to smell the boy's cap, and started on the trail made by the boy. The dog followed the route indicated by the dotted line. Between the tree and the street cars the dog followed to the right of the boy's trail, apparently because the wind had scattered sand on which the boy had walked. In the lee of the street cars he followed the trail closely. Where the boy had turned at X the dog had some difficulty, as shown by his windings. Just before reaching the huts the dog lost the trail, evidently because many people were walking about, but soon found it and followed it to the laboratory.

For information regarding the ability of dogs to discriminate between the body odors of people, Buytendijk carefully tested Albert,

a police dog. A pebble was held in the hand a short time, then thrown among many other similar pebbles 10 to 20 yards away. The dog saw and heard in what direction the stone was thrown, but he could not distinguish it by sight from the other stones. After having smelled the person who threw the stone, Albert searched for and found it many times without making a single mistake. To make the test more complex, six persons threw as many stones at the same time. After smelling one of the six persons the dog invariably returned with the stone thrown by him, showing that the dog can easily recognize individual odors of people. The last test was to determine whether Albert could associate a pocketbook with its owner. Four pocketbooks belonging to four men were laid in a row. Albert, of course, could not distinguish by sight the owner of each purse, but he made no mistake in doing so by smell. He was allowed to smell one of the men and then smelled all the pocketbooks, announcing his decision by barking. These results fully convinced Buytendijk that the employment of dogs in police departments is highly justified. However, as a result of more recent tests by German police officials, the use of dogs in helping to detect criminals is forbidden in Germany. Critics contend that the dogs were not properly tested.

In 1926 Löhner, an Austrian physiologist, used pieces of wood, alike in appearance and smell, in testing the olfactory sense of dogs. It was soon learned that a police dog can easily distinguish the wood handled by a person. While the dog was not looking a piece of wood was held in the hand, then put among other pieces which were handled only by means of forceps. The dog was next allowed to smell the hand, and was told to find and to bring the wood that had been held. Other tests, in which the pieces of wood were deodorized, showed that the dog could distinguish the pieces even if they had been touched with the finger tips for no longer than a second or two. He succeeded even when persons other than the one whose odor was to be identified had handled the wood, and even after artificial odors had been daubed on the wood, although he barked his disapproval. This police dog was able to identify the odor of a person when the wood had been put on different parts of the person's body.

To summarize, dogs, like people, can detect odors of various kinds and qualities and, in addition, are able to analyze a combination of smells and attend exclusively to one component of it. This is a power that we lack almost entirely. When we experience the stimuli of two odors at the same time we rarely detect both of the qualities in the mixture; usually one of them overcomes or masks the other, or a new odor unlike either results. The dog, and perhaps many other animals, can analyze a fusion of smells as a trained musician

analyzes a chord. In this respect, if not in the variety of smells, we are able to distinguish, our olfactory sense has degenerated.

It is well known among beekeepers that bees can easily distinguish the body odors of a person. Usually beekeepers, when handling queenbees, hold them gently and as little as possible with the fingers, because they know by experience that the workers do not like the odor from the fingers, and often kill queens excessively charged with foreign odor, such as that from perspiration. The writer discovered that a friendly hive mate can easily be changed to a strange worker by merely stroking its back with a finger.

The homing and orientation of ants have for ages puzzled the minds of observers. There are really two problems involved. First, how does a solitary forager, after she has found food at the end of a long and rambling course, find her way back to the nest? Second, how do ants follow a well-beaten ant trail to and from the nest? Many theories have been advanced to answer these questions. Chief among them are the following:

Piéron divides ants into three divisions; some follow the trail by smell, some by sight, and others by a kind of muscular sense. In some species there is a kind of muscular memory, the ants simply reversing on the homeward path all the turnings they took on the way out, like a top unwinding itself. Cornetz believes that ants have a mysterious power of registering in their bodies the general direction of their outward course and reversing it when they have found a load to be carried home. The ant behaves, in short, as if she contained a compass. This kinesthetic sense acts merely like a roughly constructed pedometer, giving the insect a vague notion of the distance traveled from the nest. Many writers claim that in part, if not entirely, ants are guided by sight in their wanderings and along the trails.

Brun gives the best and most complete general survey of the entire subject of orientation in insects, birds, mammals, and man. In regard to ants he strongly advocates the theory that they are guided by contact and by odors, although he fully discusses the various other factors involved. As to distant orientation in ants, he admits to consideration only the contact-odor sense and the sense of sight. He states that the faculty of self-orientation is in its broadest sense a primary property of living protoplasm. The higher ants are able to see the large distant objects which serve them as landmarks for finding their nests, and in a certain measure this faculty appears to serve the lower ants. The higher ants, by following a straight course from their nest, are able upon returning to deviate to the right or left, thus sometimes describing a polygon during their wanderings, but they do not possess a sense of angles, as suggested by a few writers. In the higher species a true associative memory of location

exists to a certain degree. Recognition of a known location is probably the function of the contact-odor sense, while the perception of direction is effected wholly by visual memory.

Many observers have strongly held that the sense of smell explains how ants and termites retrace or follow their tracks, and these social insects have actually been observed to lay down odorous trails, but not until recently has anyone conclusively demonstrated the part played by smell.

Henning became greatly interested in this problem, and decided to help clarify it, if possible. The many authorities on this subject are agreed that the three senses of sight, touch, and smell are involved, but the question remains as to which one of these plays the most important part. Some of the writers think that smell is the most important, but do not explain just how this sense operates, finding a difficulty in the fact that the various trails run from the nest in every direction, and apparently the same odor clings to all of them.

Henning first attacked the problem by observing the behavior of ants upon artificial paths instead of upon those made by themselves. He caused the ants under observation to crawl over paper covered with lampblack, and observed that after having traveled for a distance of 1 millimeter an ant made three strokes upon the black paper with the end of her abdomen. After they had crawled over the paper for a time or two the characteristic odor of formic acid was plainly perceptible, indicating that they had imparted this particular odor to the trail. It was later determined that they excreted this acid whenever they were running over the paper, thus giving a cue for experimental tests in which only the olfactory sense is involved. He next painted a pathway up a tree, from the ground to the highest point he could reach, with a weak solution of formic acid. The result obtained was most interesting. Even before he had made a connection by means of the acid from the foot of the tree to one of the natural runways passing from the nest, 10 to 20 ants made their way up the artificial path upon the tree, though this path had not been visited by them before. These pioneers were quickly followed by others, until nearly the whole personnel of the nest had thus been led astray by the artifice. The conclusion was drawn that the insects reacted strongly to the odor of the formic acid, which was more concentrated than that in their own bodies. The stimulus was so strong that even while the path was still moist the ants began to travel over it, though they particularly dislike to get their feet wet and always avoid damp places. Curiously enough, the same effect was produced not only by formic acid but by other chemicals having a similar odor, such, for example, as formaldehyde. This experiment also showed that it is not the smell of food which exerts the attraction but the smell peculiar to the insects themselves.

OUR INSECT INSTRUMENTALISTS AND THEIR MUSICAL TECHNIQUE

By H. A. Allard

Senior Physiologist, Bureau of Plant Industry, United States Department of Agriculture

[With 16 plates]

THE SOUNDS OF INSECTS

Most people doubtless recognize the chirp of crickets in the grass and the raucous chatter of katydids in the trees, but beyond these limited experiences the general public probably knows little of our musical insects. Yet in the immediate vicinity of Washington, D. C., more than 20 species of crickets add their distinctive notes to the great midsummer symphony of insect sounds, and about 25 species of katydids lisp and rasp from their hiding places in the grass, herbage, and tree tops. In addition, 10 or 12 kinds of grasshoppers lisp notes with their wings while in the air, or crackle along over the fields in flight, and others fiddle with their legs against their wing covers while at rest on the grass or herbage. A number of cicadas, too, of the order Hemiptera, murmur and zing in the midsummer heat.

MUSICAL IMPULSE AMONG INSECTS

The proclivity for sound-making by one method or another is a ubiquitous impulse and mood of life. The great insect kingdom has not been backward in following the same weird organic trend toward the egotisms of self-expression. The order of beetles *Coleoptera*, has evolved noise-making structures on every conceivable portion of the anatomy, including the head, mandibles, pronotum, mesothorax, forelegs, middle legs, and the elytra or wing covers. In truth, where-ever two mobile surfaces offer the least potentiality of contact with each other, noise-making structures have somehow arisen, and the necessary remodeling and sculpturing to produce file vein and scraper have somehow followed. Whatever the portion of the body involved, a marvelous plasticity of the external integuments has been shown in this great group, as if contiguous surfaces were almost aware of their proximities. At every twist and turn of the head, antennae, legs, thorax, abdominal segments, and other parts, microscopic files or

sound-rasps and scrapers have evolved, so that sound can somehow function in their lives. In the ants, too, similar sound-making proclivities have been shown in some instances. Although the ants and the beetles, even to the larval stages that know none of the moods of the sex impulse have become greatly concerned with sound production, little is known of their notes. Their sounds never constitute the poetry of earth so dear to the human mind. Moreover, many of these sounds unquestionably are not even perceptible to human ears, because they are beyond the range of audition. One must think of sound at times in terms of wave impulses, as one does of light. The sound spectrum, so to speak, may at both ends extend far beyond human auditory powers, the vibrations being too rapid at the higher extreme and too slow at the lower extreme to affect the auditory mechanism in terms of sound.

INSECT MUSIC WHICH WE ORDINARILY HEAR

We are at present concerned with only those great groups of insects which impress their sounds upon the daily consciousness of our lives. These insects are so large and so persistent in their sound making that they produce a greater volume of noise than that made by the ants or beetles. There are only two families which may at times fill our ears with sound; the cicadas, or so-called harvest flies of the order *Hemiptera*, including the true bugs; and the grasshoppers, crickets, and katydids of the order *Orthoptera*.

HOW THESE INSECTS MAKE THEIR SOUNDS

Birds are the great vocalists of the earth. With few exceptions they sing by means of a very efficient larynx within their throats. Some few, as, for instance, the nighthawk, produce noises in a unique manner with their wings while falling like a stone through the air from great heights. Others drum with their wings upon the air like the ruffed grouse, or flirt out queer bleating sounds with their tails while on the wing like the snipe. Such specialized modes put these wing or tail singers in the class with the instrumentalists like the insects. Strange it is that nature, in the case of these birds and that of a Turkestan lizard, which chirps with its tail, has somehow overlooked the throats and vocal cords, preferring for some mysterious reason to make these creatures the unique instrumentalists of their class.

Insects are never vocalists like the birds, but always instrumentalists. The cicadas or harvest flies, with their loud zinging, represent one great distinctive group of insect musicians, to which the so-called 17-year locusts belong. All members of this group make their music within specialized body cavities by means of thin chitinous mem-

branes, made to vibrate rapidly at will by a very powerful musculature. Only to the extent that it employs an internal device does this method resemble the vocal efforts of the birds. The musical apparatus of the cicada appears to represent the most complicated structure which the forces of life have evolved for sound production in the insect kingdom. Nature is frequently seen to run riot with this tendency or with that, specializing for ages upon bill, feather, or claw, producing organisms with marvelous and grotesque adornments upon every feature, and so in this instance, in which she decided to expend the forces of her inventive genius upon the music boxes of the cicadas. These are complicated in the extreme. Little was known of their structures until the great French naturalist Réaumur, as far back as 1740, gave his scrutinizing attention to their marvelous specializations, and little has been added to the understanding of it all since his day. The principle of the musical organ is that of the drum, the vibrant, membranous head of which is snapped or sprung with great frequency to produce the loud metallic sounds. Nature appears here to have seen potentialities for her infinite ingenuity and genius and to have settled down in serious contemplation to equip the cicadas with marvelous cymbals. The sounding drums or tympani are ribbed to make them strong and elastic to withstand the terrific energies of vibration to which they are constantly subjected. Not content with this, the forces of life even specialized in spacious resonant air chambers, to increase and transmit the sound, reflect it to the best advantage, or change its volume at will. It is all a matter of superspecialization, it would seem, and to what end? For some reason the forces of life decided to make the cicadas artists, geniuses in their line, in some queer organic localization of the molecular forces and impulses of life of which we know nothing.

Our more familiar insect sounds of the summertime are made by members of the order Orthoptera, including the crickets, grasshoppers, katydids, walking sticks, roaches, mantids, and others of the order. It is in this group that the musical impulse has somehow become a great impelling motive in their existence. Not all the families of this order have specialized in music, however, for the mantids, walking sticks, and roaches are little given to the production of sound for sound's sake. It is among the grasshoppers, katydids, and crickets that a veritable sensitized ear for music has developed. All these singing creatures wear their musical instruments externally on their legs or upon the wing covers of their backs.

The music is instrumental; the musicians are with few exceptions genuine violinists, or xylophone players. The more lowly grasshoppers may produce their music while flying over the fields, while hover-

ing almost stationary in the air, like the queer Carolina grasshopper, *Dissoteira carolina*, or while at rest. The majority sing while at rest by sawing their hind legs simultaneously upon the edges of their wing covers. Teeth—in some instances upon the legs, in others upon the vein of the wing covers—are made to scrape several times upon a ridge of the other member to produce the characteristic lisping sounds of the species. This action is in reality a true fiddling, even though the sounds may not be particularly musical to the human ear.

Flight stridulation is perhaps the commonest method of producing sound among the grasshoppers (*Acrididae*). Nature has recognized other potentialities here, however, and has even turned to casual ambulant stridulation, as in the case of the wingless western katydid, *Stenopelmatus longispina*. In this instance the rule that katydids sing with their wing covers is broken. *Stenopelmatus* lacks wings but not the musical impulse, and so the hind legs developed a rasp on the inner surface of the hind femur to play against short teeth or tubercles upon the adjacent sclerites and connectiva of the abdomen. This queer katydid can make its joints squeak out unique music, so to speak, while it walks, wasting no more time from the ordinary duties of life than does the whistling human workman.

In all of our common eastern katydids and crickets the base of the wing covers is the seat of the musical organs. A file vein with teeth on one wing cover and a scraper upon the other drawn over this constitute the musical apparatus. In the many green and brown katydids, the wing covers are opened a little, set somewhat at an angle, and rasped upon each other. Many species of crickets, including our pearly winged tree crickets (*Oecanthus*), raise the wings nearly at right angles to the back during stridulation—that is, when they make their sounds.

WHY DO INSECTS SING?

Insects probably make their sounds for the same reason that birds and humans sing, because they love sound, and find it a means of self-expression; it is a part of their lives. It may in some instances have a sexual significance, but the theory ascribing sound to sex in insects has probably been much overdone. The females appear to have definite sex calls which will bring the males quickly to them; but in general the males alone are musical, although there are exceptions. One acquainted with these musical creatures can no more regard every sound they make as simply of sexual utility than he can so regard the musical impulses of men.

It seems to be in the makeup of many creatures, such as our musical insects, to utilize the ubiquitous sound waves, just as certain organisms have seized upon light and analyzed it to wear it in marvelous patterns upon the integuments of their backs. Even to

explain this scientific theories have been laboriously evolved upon the basis of sexual utility; light was made the means of attracting the males and females to each other through their esthetic appreciations of colors. These finespun theories now show many weaknesses. In reality we know nothing about the impulses back of it all. There are, however, strange analogies between these organic treatments of sound and light. The males among insects are generally the musical ones; they are the ones that have most aptly seized upon the sound waves and used them in varied patterns of rhythm and tone. Likewise with light; it is the males which have usually analyzed it most carefully and made its primary colors into the most varied and beautiful patterns. Strange organic laws are here at work, of which men have little knowledge.

We speak of the garrulous human in our midst as an egotistical fellow. If katydids and crickets were judged on this basis they would be the most egotistical creatures on earth, obsessed as no others with the sounds of their own wings. Perchance some degree of elemental egotism and love of noisy self-expression may actually be the motives of their lives. Perchance back of it all there is the mood of social contact, or of abiding companionship in the advertising noise of their fellows, just as we ourselves feel the thrill of noisy crowds. Perchance it is the elemental impulse of pure art, the love of sound, tone, rhythm of music in some manifestation. We know nothing with any certainty, however, about the impulses back of it all. I have heard the snowy tree cricket chirp at the rate of about ninety times per minute all night long. Think what that means; 5,400 chirps per hour, 64,800 chirps in a 12-hour night, nearly 4,000,000 chirps in a period of 60 days, demanding the muscular energy of 16,000,000 wing-strokes on the basis of four strokes for each chirp! I have no doubt many crickets chirp millions of times in the season which constitutes their span of life. What is it all about? Sex alone does not explain it. No cricket needs to chirp himself to death—chirp a cool four million or five million times night and day in one bush, or perchance on one twig, to win the momentary attentions and embraces of a silent, lonely female in the vicinity. Here is the weird mystery of insect music, its eternal persistence, an eternal wing play in some restless rôle of life, designed, it would seem, to keep the insect content and happy while it lives along to the very threshold of old age and death.

SPECIALIZATIONS IN THE VARIOUS MUSICAL GROUPS

In the cases of the beetles and some of the ants the forces of life appear to have concentrated their energies more particularly upon modifications of the file vein. Weirdly enough, some of the beetles have been equipped with two file veins, or two mandolins, so to speak.

Furthermore, life has endowed them with the most specialized file veins known, a single file vein being in some instances furnished with as many as three different sets of teeth, coarse, medium, and fine. It would almost seem that the beetles had awakened to the possibilities of having at their command several distinctive notes; or perhaps there is a trend toward some manner of primitive musical scale such as the birds employ with their vocal cords. As yet little is known, however, concerning the sounds of the beetles, for they are too faint to impress our ear readily.

The grasshoppers, katydids, and crickets, also, have decided upon the technique of the mechanical file vein and scraper, but so far as known they have not given especial attention to noticeable modifications of the file vein which constitutes their chitinous fiddle. Nevertheless, in some instances a marvelous technique has developed which has centered around the touch-and-time relations between scraper and file vein.

THE MUSIC OF THE GRASSHOPPERS (ACRIDIDAE)

If life in its evolutions is always a matter of slow and groping trends from simplicity to complexity, one must expect to find long lines of primitive impulses and expressions prior to the finish and finesse of higher activities of living and doing. This seems to be indicated in the case of our orthopteran musicians. The more lowly grasshoppers of the family Acrididae are the more primitive musicians. When on the wing they crackle and flutter lisping sounds, although having almost no definite musical structures such as a specialized file vein and scraper. In the case of some of the sulphur-winged grasshoppers, such as the species of *Arphia*, the sound is almost of the order of a clatter, reminding one of the snapping sometimes made by pigeons in flight. It is their idea of music, perhaps, but the mechanical basis of it all is of the simplest and most indefinite sort. Just how these noisy flight crepitations are made is not even consistently agreed upon by naturalists. While the Arphias and many others must catapult themselves in great trajectories and swift aerial swoops to eke out their sounds, a few have learned to arise from the soil gracefully and hover in mid-air while they "lisp" with their wings for a few seconds. Our big gray or brown Carolina grasshopper (*Dissosteira carolina*) of the bare spots and dusty roadways is best known for this specialized hovering.

The grasshoppers of another group have decided upon a more sedentary method of making their music; they are the veritable fiddlers of the insect world. A file vein with teeth, situated either upon a large wing vein or upon a ridge of the inner thigh of the great hind leg, constitutes the musical organ, with the plectrum or scraper upon the opposite member. If the file vein is upon the leg

the scraper is upon the wing cover, and vice versa. The primitive sawing of these lowly grasshoppers is never loud and impressive, and seldom plays any noticeable part in one's experiences with the poetry of insect music.

THE SOUNDS OF THE KATYDIDS (TETTIGONIIDAE)

As in the case of the grasshoppers, the characteristic sound of the katydids is only a lisp or a rasp. Tonality, in the sense of musical pitch as the human ear judges music, plays no part in their sounds. For some mysterious reason this is a distinctive feature of the sounds of all our katydids. From the southern giant katydid, *Stilpnochlora couloniana*, to the tiniest woodland meadow katydid, *Conocephalus nemoralis*, hint of tonality such as even the tiniest crickets possess is absent. This is somehow a marvelous group behavior, provided all our morphological classifications which make it seem thus have been sound. We may think the katydids are far behind the crickets because the latter alone have acquired tonality of an order closely akin to the pitch of our own formalisms of music. It is possible to go too far in our philosophizing, however, for if the katydids merely rasp out strident noise, as our ears would judge it, they have at least specialized in the direction of a better control or more varied manipulation of the musical structures, resulting in a striking variety of notes and deliveries which none of the crickets have yet evinced.

TONALITY A DISTINCTIVE FEATURE OF CRICKET MUSIC

Our morphological classification of the katydids and crickets has, unintentionally, rigidly separated these two great families with respect to certain unique features of their stridulations. As previously stated, the crickets have somehow learned to chirp in terms of the tonality of our own music. Their notes may be recognized as having a definite musical pitch, whereas the katydids merely rasp out noise. It is a marvelous step forward in the evolution of the musical impulse as judged by human standards of audition and the enjoyment of sound. The crickets appear to have gone no further, however, for they merely trill out eternal monotones of sound in a continuous unceasing shuffle of the wing, or they merely break it up into more or less regular, rhythmic intervals, to produce their chirping soliloquies and synchronal concerts. True musical pitch alone distinguishes their music from that of the conehead, *Neoconocephalus*, among the katydids. Whereas the meadow katydids, *Orchelimum*, some of the amblycoryphas, and the angular-winged katydids, *Microcentrum*, have introduced new trends of composition and variety into their songs, even as much as some of the less musical birds, the crickets, strangely enough, have seemingly established their distinctive genius on the basis of tonality alone. The same type of musical structure,

a file vein and scraper, is at their disposal, yet no departures whatever appear to have evolved from the simple monotone or the rhythmic chirp in the direction of producing variety with these elements. Every cricket trills unceasingly or chirps intermittently. Should a cricket with tonality at its command learn to trill and chirp as efficiently as the little Uhlers' katydid, or strike a series of separate musical tones with the technique of the larger angular-winged katydid, cricket music would at once become a marvelous rendition of tinkling tones and chimes surpassing anything we now hear in their musical accomplishments.

THE MUSICAL TECHNIQUE OF THE CRICKETS AND KATYDIDS

It is common knowledge that crickets trill and chirp, but the technique of the production of the sound has been little studied. It would seem that remarkable specializations have taken place, making the technique of one katydid or cricket entirely unlike that of another.

In all our eastern crickets and katydids the musical apparatus has been shown to be a typical file vein on one wing cover and a scraper to draw over it on the other. This mechanical device seems fairly simple, but the manner of using these frictional structures to produce sound has become very varied.

It would appear that the sound is generally if not always made by the forward stroke of the scraper or plectrum over the chitin bars. The wing covers or elytra are first separated a little and set so that the scraper is at one end of the file vein. They are then brought together swiftly so that the scraper glides forcibly over the teeth to the other end. The wing covers have now advanced to their extreme closing position. When the wings are drawn back again for the next note or rasp an interval of silence intervenes. It is important to keep these steps in mind in an analysis and understanding of the various sounds which our crickets and katydids are capable of producing as their distinctive "songs" or stridulations.

THE CONTINUOUS TRILL OR BUZZ

The simplest and one of the most common methods of stridulation appears to be that in which the scraper is run at high speed for indefinite periods over the file vein. Many crickets and katydids trill in this monotonous manner for hours at a time. The writer feels that, in most instances, the sound depends upon the forward stroke alone of the scraper upon the file vein. The slight interval of silence between these positive strokes gives the noticeable character of quaver or tremolo which the trained ear can usually detect. Many of our crickets have this continuous high-speed habit of stridulation,

as the tree crickets, *Oecanthus latipennis*, *O. pini*, *O. nigricornis*, *Phylloscyrtus pulchellus*, and *Nemobius palustris*. Among the katydids, subfamily *Copiphorinæ*, this method of stridulation is the method of the species *Neoconocephalus robustus*, *N. retusus*, *N. nebrascensis*, *N. palustris*, *N. triops*, and others. In the case of the katydids all musical pitch or tonality as judged by human ears is absent. The rapidity of the forward strokes in this continuous play of the scraper across the file vein varies greatly, being relatively slow, it would appear from its snappy notes, in the case of the cone-head, *N. retusus*, but exceedingly fast in the case of *N. robustus*, whose notes may have the even, ear-splitting hum or drone of a rapidly revolving saw. To produce this keen, smooth, hum some thousands of forward strokes of the scraper per minute must be made upon the file vein. Few, if any, of our musical insects would seem to move their wings with such frequency as does this big, powerful katydid. At times the writer has wondered if this katydid were the exception to our rule that the forward stroke of the scraper alone produced the sound. Nature always evolves in terms of all potentialities, and sometimes, perchance, we shall find both backward and forward strokes producing sound, as in the case of most of our own violin music.

DISCONTINUOUS STRIDULATION: INTERRUPTED CHIRP OR RASP

An interruption of this continuous habit of stridulation into distinct intervals of silence and sound is a common feature of the insect's behavior in singing. This produces the chirp or interrupted rasp characteristic of a great number of crickets and katydids. The interval of sound may be long or short, regular or irregular; all these habits of rhythm actually occur in one cricket or another, and in some of the katydids. It must be remembered that each chirp is the result of several rapid strokes of the scraper upon the file vein. The number of strokes in a chirp may be few or many, constant or variable. If with regular intermissions of silence, we have the markedly rhythmic method of chirping so characteristic of the snowy tree cricket. If the wing strokes are many and inconstant or variable, we have the long-drawn, melancholy sounds of the tree crickets, *Oecanthus angustipennis* and *Neoxabea bipunctata*, with no hint of uniformity or measured beat or rhythm. In the height of its singing period in the heat of August the musical musings of the tree cricket, *Neoxabea bipunctata*, are of this order, as if a continuous habit of trilling were merely being broken up irregularly by very brief intervals of silence anywhere, at any time. On the other hand, one who has heard the regular, rhythmic, solemn chirpings of the snowy tree cricket, *O. niveus*, can not but be impressed with the marvelously nice time relations of it all. This regularity indicates

a fundamental treatment of the elements of the chirp, that is, of the forward strokes which produce the component sounds. There is no doubt but that the cricket counts, so to speak, or that at least its physiological mechanism is somehow accurately set to produce just so many strokes in each chirp, otherwise rhythmic regularity could not obtain with the precision this cricket observes so marvelously in all its measured chirping. B. B. Fulton has noted this nice regularity in the case of the chirps of the snowy tree cricket, *O. niveus*. In one Oregon race, which he studied, the number of wing strokes was four; in another race, according to his observations, only three. It is probable that the wing strokes of this cricket do not often exceed four in each chirp. On the other hand, the wing strokes of the jumping tree cricket, *Orocharis saltator*, unquestionably exceed this number, probably being at least six for each chirp.

THE SINGLE-STROKE CHIRP OR RASP

We have considered the long, continuous trill, in which the successive forward strokes of the scraper over the file vein are very rapid, producing in some instances an almost smooth hum or drone of sound. We have seen where this is broken into separate sound intervals, each chirp or rasp composed of a number of forward strokes of the scraper, which may be few or many, constant or variable, in their sequences.

We will now consider a few instances in which the separate chirps or rasps are made by a single stroke of the scraper over the file vein. In reality this is the result of an extreme slowing down of the continuous habit of trilling. It is the most lethargic habit of stridulation in this category of methods of using the scraper upon the file vein. The scraper is drawn at comparatively long intervals. It is a most unusual method of stridulation among our true crickets (*Gryllidae*). In all my studies of this fascinating subject I have found but one cricket which has adopted this single-stroke method of "singing." The musician is one of our tiniest bush crickets, *Anaxipha exigua*, a species scarcely more than three-sixteenths of an inch in length of body. Its file vein and scraper are of microscopic proportions on its tiny, delicate wings. Naturally the sound struck off is thin and high pitched, one of the highest notes of all our crickets, and almost beyond the range of my own audition, which has been trained to be highly selective and acute with reference to insect sounds. From the smooth, clear character of the almost microscopic sounds of this cricket, so to speak, I have long ago predicted it would be found that each sound *ti*, in its tinkling song *ti-ti-ti-ti-ti* is made by a single draw of the scraper over the file vein. This was not definitely established until the summer of 1928. The

strokes follow one another at a rate of from 125 even up to 300 per minute. Owing to the microscopic character of the musical structures and the brief period of the note produced by the single forward movement of the scraper over such a microscopic file vein, the notes *ti* are strikingly smooth and tinkling, in reality little more than points of sound. Naturally there is no quaver or tremolo in the notes, as in the case of those chirping crickets where the chirp is made up of several forward strokes of the scraper. This is a most remarkable technique and marks the extreme of slow speed in the production of sound by the crickets. So far as my experience goes it is the accomplishment of *Anaxipha exigua* alone.

In the katydid family *Tettigoniidae*, at least, one cone-headed katydid, *Neoconocephalus ensiger*, of the North, produces in a similar manner each *tsip* of its continuous untiring song tsip-tsip-tsip-tsip-tsip-tsip-tsip with a single forward stroke of the scraper upon the file vein, at the relatively slow rate of about one hundred and fifty to two hundred times per minute. On the other hand, the big cone-headed katydid, *Neoconocephalus exiliscanorus*, like the snowy tree cricket, for each quavering rasp—*dzeet*—employs several wing strokes.

STRIKING THE INDIVIDUAL TEETH OF THE FILE VEIN TO PRODUCE SOUND

There is yet another possibility in this slowing down in the process of producing sounds by drawing a scraper over the teeth of the file vein. It involves a movement so slow and nicely controlled that the teeth themselves are struck separately to produce a leisurely series of 30 to 40 sounds or clicks. Remarkable as it may seem a single katydid, the larger angular-winged katydid, *Microcentrum rhombifolium*, has adopted this procedure, and I know of no other katydid that has done so. A remarkable feature of this method of stridulation is the loudness of the notes struck off by tapping these almost microscopic teeth, but life is eternally doing many things to surprise us. It is, perhaps, not more remarkable than to see the thin, transparent wings of a snowy tree cricket throwing off surprising volumes of sound from far smaller teeth, so that its chirp can be heard hundreds of feet away. None of the crickets have proceeded in this direction any further than to make their notes with a single stroke over the entire file vein, as the tiny *Anaxipha exigua* has done. Nevertheless, this is a potentiality for the crickets as truly as for the katydids. It is quite possible that a more thorough study of the thousands of musical insects of the world will yet reveal this specialized technique among some of the crickets. It is a marvelous accomplishment, and should tonality or musical pitch still obtain one would expect to find a purity of tone struck from each slender tooth as lively and as vibrant as any

musical sound life has ever evolved. If the little cricket, *Anaxipha exigua*, can produce musical tone or pitch in a single forward draw of the scraper over the microscopic teeth of the file vein, it is natural to assume that each tooth is adding its single tone to this composite note which involves all the teeth to produce those points of sound constituting its characteristic chirp.

SONGS OF THE MEADOW KATYDIDS ORCHELIMUM AND CONOCEPHALUS, SUBFAMILY CONOCEPHALINAE

The katydids alone appear to have evolved rather intricate little songs, combining in one way or another both fast and slow manipulations of the scraper over the file vein. It is evident that this combination is possible in the direction of variety, and that the musical sense of life has strangely felt it and made special use of it. Some of the meadow katydids, *Orchelimum*, as, for instance, the pretty pine-tree katydid, *O. minor*, have been content with brief lisping phrases s-s-s-s—s-s-s-s-s, making use of a series of wing shuffles for each phrase. This is merely a counterpart of the leisurely chirp of the cricket, in which there are several component strokes of the scraper over the file vein for each phrase. The majority of the Orchelimums, however, have brought more complexity into their running songs. They have introduced a series of staccato lisps, *tsip*, involving single wing strokes of very slow delivery, to precede the longer monotone in the production of which the wings fairly hum or buzz with their rapid contacts of the scraper over the file vein. The normal song runs thus: Tsip-tsip-tsip-tsip-tseeeeeeeeeeeeee, tsip-tsip-tsip. The majority of the Orchelimums have adopted these more complex time relations.

Among the smaller meadow grasshoppers, *Conocephalus*, which are closely allied to the Orchelimums, we find combinations of fast and slow time relations other than those the Orchelimums have adopted. The smaller meadow katydid, *C. strictus*, simply "sings" at high speed with its constant lisping monotone s-s-s-s-s-s-s-s-s-s-s-s-s, in a way similar to that of such coneheads as *Neoconocephalus retusus*, *N. triops*, *N. robustus*, and others. The smaller meadow katydid, *C. fasciatus*, like most of the Orchelimums, begins with a number of staccato lisps, before speeding up with the final lisping monotone, tip-tip-tip-tseeeeeeeeeeee. *C. brevipennis* uses a minimum of only 1 to 3 single wing strokes which precede one, two, or three brief, faint, high-speed lisping phrases. The song may be expressed thus: tip-tip-tseeee-tseeee-tseeee. The phases are very brief. In the case of *C. nemoralis*, the song is rather distinctive. A series of very rapidly produced staccato lisps, making an almost continuous monotone, precedes a run of 2 to 30 or more very brief, lisping phrases, before they are again repeated. It is seen from these examples that the Orchelimums

and their tiny relatives, the species of *Conocephalus*, have far surpassed the coneheads and all the crickets in establishing new formalisms in their "songs." The crickets and coneheads have established their songs mainly on the basis of uniform time-relations, making the rate of repetition of the sound-stroke of the scraper upon the file vein more or less specific for each species. They trill in long, dreamy, monotones, or chirp or rasp in more or less rhythmic accents, but there are no interminglings of the two elements. Should a cricket with the tinkling bell-tones of the jumping tree cricket, *Orocharis saltator*, adopt the varied time relations of the big meadow katydid, *Orchelimum vulgare*, in its chirpings, combining a series of clear vibrant single-stroke chirps with a brisk, quavering, monotone trill, we should find our mechanical insect music of a very superior order of rendition, and showing striking analogies with the vocal renditions of some of our warblers and sparrows. Even as their accomplishments stand to-day, the enlivening jingling trill of the chipping sparrow is scarcely more involved than the trillings of some of the crickets, and the song of the grasshopper sparrow is decidedly insect-like in its delivery and intonation.

SONGS OF THE TRUE KATYDIDS, PTEROPHYLLA, SUBFAMILY PSEUDOPHYLLINAE

The classic katydid singer of our poetry is the big arboreal fellow, *Pterophylla camellifolia*. He is the maker of those mysterious raucous chatterings in the trees which have made the nighttime sweet and companionable to many a human soul acquainted with the poetry of country life. Who among us can not say with Oliver Wendell Holmes,

> I love to hear thine earnest voice,
> Wherever thou art hid,
> Thou testy little dogmatist,
> Thou pretty Katydid!

"For there is no sadness in the earth's minstrelsy," as C. V. Riley once wrote. The gods alone made the katydids, and let us hope man will not have any reason to destroy them soon; man may make towns, but the countryside and its crickets and katydids are the musings of the gods themselves. It is to the musical insects that I owe much of my love of poetry; yes, and truth as I would measure it in terms of my science. I am a better scientist because I have known katydids and their nocturnal accents in New England, "squă-wăk′, squă-wă-wăk′," as Snodgress has so aptly interpreted it. The weird musings of these leaf-winged creatures bent upon an "egotistic love of song," as Scudder saw the murmurings of the crickets, inspired Henry S. Cornwell to take up his sonnet lyre and create a worthy Petrarchan sonnet "To the Katydid." Some one once asked what

good are crickets and katydids, and I replied, to inspire a finer poetry and philosophy in the souls of men than we now know. Long after our mechanical madness shall have worn off and our age of hurry and mechanistic musing has been forgotten, the crickets and katydids will bespeak the same rare and refined poetry to those who shall pause to feel and interpret it in terms of the human soul. What I love about these great fellows is their leisurely way of expressing themselves hour after hour in two or three simple rasping accents, as harsh and as grating near at hand as any insect note on earth, perchance. There is no hint of the machine-like expenditure of energy such as the big conehead, *Neoconocephalus robustus*, drones out with all the speed its body can command to drive the scraper over the file vein. As with nearly all of the larger katydids, each syllable is the result of a single forward stroke of the scraper over the file vein. The big true katydid has even given up active flying, it would seem, and has reduced its notes to comparatively few leisurely deliveries per minute, perhaps 20 or 25 phrases, each one involving only 2 or 3 strokes of the scraper upon the big file vein. It would appear as if the big fellows were tending toward some lethargic condition, where as little expenditure of energy as possible must be made to send its song to the ears of its fellows in some mood of social companionship that the forces back of its life demand. Caudell first reported that the female of this species, when handled, also stridulated somewhat like the males, and I also have observed this habit with this katydid. At the time Caudell wrote he did not know whether or not the sounds were ever emitted in nature voluntarily. I may state that I have found the females of other species of katydids emitting characteristic call notes of their own accord out of doors. These call notes appear to be of the nature of true sex calls or invitations to the males, for a number of these in every instance at once congregated about her, some of them flying from the shrubbery around. I have observed this behavior in females of one of the bush katydids, *Phaneroptera curvicauda*, the round-winged katydid, *Amblycorypha rotundifolia*, and the larger angular-winged katydid, *Microcentrum rhombifolium*. According to W. J. Baumgartner, the females of our common mole cricket, *Gryllotalpa hexadactyla*, have a rather loud distinct chirp, used as a note of recognition in their dark burrows. The females of a Porto Rican species, *Scapteriscus didactylus*, are said also to possess poorly developed stridulatory organs, and probably call or stridulate in some manner. It would seem that some of the females of our own musical insects are inclined to the moods of art as well as the males, a tendency which has become highly developed in some exotic species.

SONGS OF THE KATYDIDS PHANEROPTERA, AMBLYCORYPHA, AND MICROCENTRUM, SUBFAMILY PHANEROPTERINAE

In this subfamily fall many of our largest and finest katydids as judged by their elegant forms, their size, the exquisitely leaf-like nature of their wing covers, and other features. In the genus *Phaneroptera* and the closely related *Inscudderia*, we have trim, narrow-winged forms, the *Phaneroptera*, partial to the low herbage zone, but, strangely enough, the Inscudderias are confined almost entirely to the green crowns of the Cypress trees, *Taxodium distichum*. The species of *Phaneroptera* are, in my judgment, the least musically inclined of all our katydids, and in most instances appear to have lost the habit of frequent, persistent rasping. Now and then they rasp out a keen incisive zeet, or three successive phrases, zeet, zeet, zeet, and let it go at that, perhaps for minutes or hours. Rarely have I found them sitting down to the serious business of rasping off so many methodical notes per minute, like tuned-up organic machines bent upon a fixed number per minute of revolutions or scraper-strokes. The Phaneropteras "sing" at irregular periods and infrequent intervals, in moods which no one but their own race can understand. In some instances, however, they have learned to vary their notes, as I have reported in the case of the Texan bush katydid, *Phaneroptera texensis*. This katydid can produce at will a loose wing shuffle, sounding the phrase sh-sh-sh-sh, occasionally repeated and rather soft and silken, or it can produce a loud, rasping, incisive *zeet-zeet-zeet*, slowly delivered. In our preceding analysis of the technique of stridulation, I have indicated what the single stroke does, and what a rapid succession does in the synthesis of the chirp or rasp. These two notes simply represent both methods as isolated accomplishments, but interesting enough, having no constant relation to each other in a definite song, as in the case of the meadow katydids, *Orchelimum* and *Conocephalus*.

In the genus *Amblycorypha* we have a highly developed musical technique, which in the case of the little Uhler's katydid surpasses the musical accomplishments of any katydid in our country in the complexity of its song. The round-winged katydid, *A. rotundifolia*, merely lisps at intervals a leisurely silken monotone sh-sh-sh-sh-sh, these lisping phrases being of no definite length. In the last analysis it is but a slow movement of the scraper over the file-vein at uncertain intervals and for indefinite periods of time. The big oblong-winged katydid, *A. oblongifolia*, expends much less energy in song, it would seem, for its rasps though strong and incisive are repeated at the rate of only 15 to 20 per minute. Each phrase, sounding something like it-z-zic—it-z-zic, appears to be made by only two or three rapid strokes of the scraper.

The little Uhler's katydid, *A. uhleri*, has in a surprising manner broken away from the simpler formalisms of the group, and has attained a more versatile running song than any other katydid I have become acquainted with. Its notes begin with a soft, prolonged, lisping, crooning monotone, produced by a rapid shuffling of the wings. This soon runs into a succession of short staccato lisps—itsip-itsip-itsip—and terminates with a succession of brief shuffling phrases, sh-sh-sh-sh—sh-sh-sh-sh—sh-sh-sh-sh. Additional staccato notes, tip—tip—tip, sometimes follow these closing phrases. It is evident that a notable step toward variety has been built up in this song around the simple elements of the continuous monotone, with interruptions of its course, combined with the single-stroke play of the scraper. In a sense the song combines in a somewhat modified form the elements of the notes of the round-winged katydid, *A. rotundifolia*, and the oblong-winged katydid, *A. oblongifolia*. The phrases it-sip bear certain analogies with the it-z-zic of the oblong-winged katydid, and in their quality and technique the phrases sh-sh-sh-sh are almost the counterpart of those of the round-winged katydid. The staccato notes tip-tip-tip-tip remind one of the moods and modes of the meadow katydids, *Orchelimum* and *Conocephalus*.

In the genus *Microcentrum* we have two of our finest and largest katydids, one the smaller angular-winged katydid, *M. retinerve*, almost strictly arboreal and exceedingly wild and restless, and the larger angular-winged katydid, *M. rhombifolium*, one of our tamest, most docile and sedentary species. The former is rarely seen, for it is active only at night and is not especially common in the Washington district. Its stridulations, which are very distinctive, now and then advertise its presence in the trees after dark. The notes consist of several lisping or rasping phrases rapidly delivered, each successive phrase being shortened usually thus: Sh-sh-sh-sh—sh-sh-sh—sh-sh. The usual number is three, although less rarely four may be given. In low temperatures only one phrase may be delivered. This succession of phrases is given at very irregular and infrequent intervals as the creatures are roaming over the crowns of the trees, usually not oftener than one to three in a minute. The larger angular-winged katydid is a denizen of the low herbage and shrubbery, and, like the robin and many other birds, appears to prefer close contact with the domestic plantings of man. It is far more common in cities and towns and around house plantings of shrubs and trees than in wild, wooded situations. One note is a loud tsip, tsip, delivered at the rate of twenty to thirty times per minute in a very leisurely way. This is simply the result of a single closing wing stroke, and is frequently indulged in at given intervals by all the creatures in a locality. The true song which may then follow, first by one, then by another, far and near, is the series of long-drawn

crepitating clicks which I have already described as being one of the most remarkable accomplishments of any katydid known, because it is veritably a tapping upon the individual bars of its chitin xylophone to produce its music. These slow, clicking notes may be heard throughout all the parks and in the street trees everywhere in the city of Washington during August and much of September.

SONGS OF THE KATYDIDS OF THE SUBFAMILY DECTICINAE

The katydids of this subfamily are large, peculiar-looking insects, with usually very short tegmina or wing covers. They are known as the shield bearers, because the hind portion of the pronotum is in some instances greatly prolonged backward to cover the basal segments of the abdomen. Nature was anxious either to make this group musicians or to keep them musicians. If evolution has been with them a process of reducing the wing covers from structures that were once longer, this reduction has progressed to the very seat of the musical organs themselves, these alone remaining. The males have only the shrilling or musical organs left as hints of wings. In spite of this modification they are musical enough and shuffle off long, irregular notes sh-sh-sh-sh-sh-sh-sh-sh when they please. There is much to be learned of the habits and songs of these interesting dark-hued katydids, and a fine field for original study of their musical habits is open to close-observing field naturalists west of the Mississippi River, where the main distribution of this subfamily appears to center.

SONGS OF THE MOLE CRICKETS, SUBFAMILY GRYLLOTALPINAE

These odd crickets are known as mole crickets because they burrow like moles in the soil and are very rarely seen. In most instances they appear to have the chirping habit of stridulation, producing low-toned, deep, gruff chirps—grrrr—grrr—grrrr, oftentimes in wet, marshy habitats. Many people may have heard these notes at their feet, but the chances are that the notes were attributed to frogs; for how rarely does the layman know frogs from crickets as they sound their presence to his ears? In truth, the observant Thoreau, excellent field naturalist that he was, mistook the notes of these crickets for the voices of frogs, and did not learn of his mistake for many years. Gilbert White, in England, likened the notes of the European mole cricket, *Gryllotalpa gryllotalpa*, which is now established in eastern America, to the callings of the nightjar, a bird of the whippoorwill family. Kirby and Spence noted the same likeness. Scudder, speaking of the mole cricket, *G. hexadactyla*, stated that the pitch of the chirps was above middle C. So far as my own observations go, its notes have the lowest pitch of any cricket notes I have ever heard, but tonality is present, as in all cricket sounds.

SONGS OF THE BUSH CRICKETS CYCLOPTILUM, SUBFAMILY MOGOPLISTINAE

Very little appears to have been written concerning the stridulations of the species of *Cycloptilum*. According to Rehn and Hebard the notes of the species *C. squamosum* and the more southern race, *C. squamosum zebra*, are brief intermittent chirps.

SONGS OF THE GROUND AND FIELD CRICKETS, SUBFAMILY GRYLLINAE

In the genus *Gryllus*, which includes several recognized races of the single native species, *Gryllus assimilis*, the typical chirping habit appears to be the rule. However, I have reported a physiological race with a habit of continuous trilling, which I found in northern Georgia. I have heard one individual with the same trilling habit in the Washington, D. C., populations. An introduced species of *Gryllus*, the European house cricket, *G. domesticus*, chirps casually and intermittently, but with less vim than our own native species.

In the genus *Nemobius*, comprising many of our smallest ground crickets which have become adapted to a wide range of habitats, from dry fields and woods to cold sphagnum bogs, several methods of stridulation prevail. A continuous stridulation is the behavior of *N. palustris* and *N. carolinus*. The habit of intermittent stridulation is characteristic of *N. ambitiosus* and *N. fasciatus*. Physiological races of the latter appear to have specialized in somewhat different methods of stridulation, for I have found colonies in different localities and habitats trilling distinctive notes. One mode of stridulation is a very high-pitched, prolonged trill, ti-ti-ti-ti-ti-ti. The succession of the wing strokes appears to be very slow, so that each syllable ti represents a single draw of the scraper over the file vein. Another mode of stridulation is a brief, intermittent chirp or trill, tiiii—tiiii—tiiii—tiiii, which appears to be a more or less rhythmic sectioning of a very rapid trilling movement of the wings.

In the genera *Hygronemobius*, *Anurogryllus*, *Miogryllus* and *Gryllodes* every variation prevails, from the continuous quavering trill to the distinctly intermittent chirp. The species *Hygronemobius alleni* and *Anurogryllus muticus* are content with the unbroken, high-speed trill. The cricket, *Gryllodes sigillatus*, introduced from the Tropics and occurring commonly in greenhouses everywhere, and one of the most energetic of crickets, may be said to trill slowly or chirp hurriedly, as one cares to see it. The note is squeaky and continuous, like the shrill squeak of a rusty hinge, produced in a long fast series at a rate of 400 to 500 per minute, or about as fast as one can possibly count. I am inclined to believe that these individual chirps are single strokes of the wing and that a little more speed, up to 800 or 1,000 strokes per minute, would run them into the typical

quavering, continuous, trilling monotone. The little native ground cricket, *Miogryllus verticalis*, has a definitely pronounced habit of chirping, the chirps being often rather prolonged and with very brief intermissions, so that only 38 to 40 are produced per minute. It is a marvelous versatility of life that has evolved these varied modes of stridulation, in the one instance by simply slowing down or speeding up the wing strokes in a continuous series, and in the other by sectioning a series into regular or irregular components comprising several wing strokes for each chirp.

STRIDULATIONS OF THE TREE CRICKETS, SUBFAMILY OECANTHINAE

The genus *Oecanthus* includes a considerable number of species as our morphological classifications have separated them. Unquestionably there is much intergrading within the group, however, and some of the forms show close affinities in many features. In the East the snowy tree cricket, *Oecanthus niveus*, is the only rhythmically chirping form so far as very definite intervals of sound and silence are concerned. In some mysterious manner its chirps are so nicely regulated into unit sections, so to speak, as to comprise a definite number of wing strokes per chirp, as if these were accurately counted. Some have doubted the capacity of these crickets to appreciate rhythm sufficiently to synchronize their chirpings. This, however, appears not one whit more difficult for me to grant than to understand how they can measure or count a definite number of strokes for each chirp. Whether or not it is a conscious or unconscious appreciation or measure of time intervals, it is somehow a marvelous adjustment of the physiology or psychology to the time relations involved. If each chirp has the rigid pattern of three strokes or four strokes of the scraper over the file vein, this is somewhere, somehow, the basis upon which its synchronous chirpings must be built.

The narrow-winged tree cricket, *O. angustipennis*, and Davis's tree cricket, *O. exclamationis*, are probably not far separated in their lineage, and both have the same irregular mode of intermittent chirps; that is, the chirp may range from 2 to 10 seconds or more in duration. At very high air temperatures, conducive to energetic expression, these chirps appear almost as irregular trills, sectioned from the long, continuous monotone by momentary interruptions at irregular intervals.

The continuous quavering trill is characteristic of the broad-winged tree cricket, *O. latipennis*, the black-horned tree cricket, *O. nigricornis* and its variety, the four-spotted tree cricket, *O. nigricornis quadripunctatus*, and the pine tree cricket, *O. pini.*

In the genus *Neoxabea* the single species *N. bipunctata*, known as the two-spotted tree cricket, chirps in the same irregular droning

manner, as does the narrow-winged tree cricket, *O. angustipennis*, but with stronger, deeper-pitched intonations. This cricket may often be heard in the region about Washington, but it is a rare and unusual cricket to meet. Its lingering chirps often may not exceed a rate of 2 to 10 per minute.

STRIDULATIONS OF THE BUSH CRICKETS, SUBFAMILY TRIGONIDIINAE

It would appear that one species of *Anaxipha*, *A. imitator*, among the tiniest of our crickets, has, so far as observations have revealed, the habit of intermittent stridulation. The common little *Anaxipha exigua*, the only species in the region about Washington that has a northward distribution to New England, may be said to trill so slowly as to allow the separate wing strokes for each tinkling ti, in its leisurely succession ti-ti-ti-ti-ti-ti, to be readily counted. If we can still consider this the method of continuous trilling, the speed of the forward stroke of the scraper has been reduced to only 200 to 300 per minute.

Two species of *Cyrtoxipha*, *C. gundlachi* and its variety, *C. columbiana*, appear to possess the habit of intermittent stridulation. In the latter species, which occurs in the region of Washington, the shrill, high-pitched chirp is decidedly measured and rhythmic, and I have noted a marked synchronous chirping in some colonies.

The beautiful, distinctively colored tiny red-headed cricket, *Phylloscyrtus pulchellus*, trills in a faint, unbroken, long-continued, quavering monotone.

STRIDULATIONS OF THE LARGER BUSH CRICKETS, SUBFAMILY ENEOPTERINAE

The bush cricket, *Hapithus agitator*, is one of the most sedentary of all our crickets. It always appears lazy and little inclined to sing, and when it does it utters a very weak, wavering, uncertain, continuous stridulation, which can be heard only a few feet away.

In the genus *Orocharis* we have the jumping bush cricket, *O. saltator*, an exceedingly fine and musical species of the shrub-and-tree zone. The note of this cricket is a clear, shrill, bell-like chirp, somewhat lingering or prolonged, and delivered at the leisurely rate of 35 to 40 times per minute, even on warm evenings. The notes of the different singers have a widely varying pitch, so that when a group is chirping on a calm autumn night a pleasing play of vibrant tones, as clear as if struck from glass, appears to enliven all the trees around. The notes are in a far higher pitch than the notes of the snowy tree cricket, and are far more ringing, bell-like, and smooth. They are never synchronal, however, each cricket chirping as he pleases, in a joyful, leisurely way.

SYNCHRONOUS CHIRPING OF CRICKETS AND KATYDIDS

Many insects not only chirp in small groups and colonies but a number of them appear inclined to bring their notes into synchronism with those of their fellows. This procedure seems somewhat remarkable, and some with no first-hand information worthy of serious attention have been inclined to question the behavior. Synchronous chirping is an undoubted fact, however, and there is no reason why an insect or a bird should not in some instances perceive rhythm and keep step as well as a human being. The snowy tree cricket, *Oecanthus niveus*, affords the best example of this behavior. B. B. Fulton, who has carefully studied various races of this cricket throughout its range, is as convinced as am I that this cricket prefers to chirp in unison with its fellows. By an imitation of its notes I have led chirping individuals to speed up their rate noticeably, in order to synchronize their chirps with my mimicry. I have observed the same habit of synchronous chirping in groups of the little tree cricket, *Cyrtoxipha gundlachi columbiana.* I happened upon one of the most remarkable instances of a perfect synchronism when I met a group of the cone-headed katydids, *Neoconocephalus exiliscanorus*, rasping out their dzeet—dzeet—dzeet. From time to time one or another musician would pause after the usual series of 18 to 25 notes. When it again joined the chorus, its notes were always perfectly timed to accompany those of the other singers. Here, for long periods of time, this dropping out and taking up the musical play was indulged in, but always with the same perfect synchronism with its fellows. Other crickets and katydids have the habit of intermittent stridulation, but I have never observed with them the least tendency toward keeping step in the time sequences. So far as I can determine, the common field cricket, *Gryllus assimilis*, the European house cricket, *G. domesticus*, the jumping tree cricket, *Orocharis saltator*, the mole crickets, and the chirping species of *Nemobius* show no indications of synchronous chirping. Likewise, the conehead, *Neoconocephalus ensiger*, which chirps intermittently in colonies everywhere in the North shows no tendency to synchronization such as I have observed so highly emphasized in the chirping behavior of *N. exiliscanorus.* There is no reason whatever to question this behavior in creatures below man, for among the birds most remarkable instances of synchronized calling and singing have been recorded in the literature. There may be some simple biological or physiological reason back of it all. In the case of the snowy tree cricket, lack of thermal uniformity of the atmosphere seems to act unfavorably upon the synchronizing impulse, for it is well known that the rate of chirping of these crickets shows exceedingly nice correlations with the temperature. The cold machinery of their stridulatory

mechanism appears to be eternally within the grip of the temperature level, compelling the same singers to slow down their notes from 135 chirps per minute at 70° F. to only 62 chirps per minute at 54° F. So mechanized are these little insects in this respect that they have been termed thermometer crickets, and formulae have been devised to compute the air temperature from the rate of their chirping. The niceties of the matter are, however, not so simple as this, for each race has a physiological rate of its own, and this, as well as the individual rate and still other factors, must be carefully worked out before our crickets can begin to serve as very efficient audible thermometers with their rhythmic chirps.

VARIATIONS IN THE NORMAL METHOD OF MUSICAL EXPRESSION

Now and then, for some unexplainable reason, a cricket or katydid develops an abnormal method of musical expression. Considering, however, the countless numbers which one may hear in his lifetime this is of very rare occurrence. A few years ago I came across a big conehead, *Neoconocephalus exiliscanorus*, chirping with the tonality or pitch of a cricket—one of the most unusual departures that has ever come to my notice. It has always been a mystery to me why the notes of all the katydids should so consistently lack musical pitch as our ear defines it, while all the crickets "sing" with a musical pitch or tonality. There is no more musical quality in the squă-wăk of the true katydid, *Pterophylla camellifolia*, or the notes of the Phaneropteras, Amblycoryphas, Microcentrums, Orchelimums, species of *Neoconocephalus*, *Conocephalus*, etc., than in the harsh noise made by scraping a knife blade smartly across the teeth of a comb. In spite of this mystery of the complete lack of tonality in the notes of all the katydids, the katydid I have mentioned suddenly became as a chirping cricket. Microscopic examinations of the file-vein and scraper revealed nothing in the least abnormal, and I am still profoundly nonplussed by this riddle of life as the musical crickets and katydids have consistently made it.

At another time I had placed in my bedroom a musical jumping tree cricket, *Orocharis saltator*, that I might rest and dream to the tune of its silvery, ringing chirps, and experience that sweet poetry of companionship with the night sounds that leads almost to those finer ecstacies of religious awe. Suddenly, in the night, I was awakened from my sleep by an exceptional tone struck off by this cricket; a loud clear scintillant note devoid of all the quaver which usually attends its tremulous chirp. There were not many of these notes, but I realize now, from later studies of the smooth, clear tones of the little bush cricket, *Anaxipha exigua*, that I had probably heard the jumping tree cricket, in some unusual mood, strike off a few of

its notes, each made with one draw alone of the scraper across the file vein. These notes are very brief, to be sure, scarcely more than mere dots or points of sound, but they are as smooth and as ringing and scintillant as tones struck on glass or upon a xylophone. Marvelous is the uniformity of life, however, when, of all the hundreds of thousands, perhaps millions, of crickets I have listened to in my experience, so few have failed to chime anything but the distinctive notes of the species. These rare instances, however, represent potentialities within the attainment of the creatures, and potentialities somehow seek their fulfillment with strange insistence at every turn.

PHYSIOLOGICAL SPECIES AND THEIR STRIDULATION

Our established systems of classification recognize specific difference mainly on the basis of morphological distinctiveness. This basis works fairly well at times, but at other times the criterion appears to be poor and uncertain. The forces of life are not working on the basis of definitely predetermined concepts resting upon a structural or morphological basis alone, but deep down in the physiological complex as well. The field naturalist is doomed to despair so soon as he accepts as clear-cut and final most morphological concepts of the patient laboratory analyst. The more intensively we study the localized facies of life, the more do we find varietal distinctiveness, racial distinctiveness, on and on, even to individual distinctiveness. The big field cricket, *Gryllus assimilis*, may show no obvious morphological distinctiveness in the region between Massachusetts and Georgia, yet in the Georgia piedmont district near Gainesville I found an early spring race of this cricket with a habit of weak, continuous trilling, reminding one of the trill of the four-spotted tree cricket, *Oecanthus nigricornis quadripunctatus.* Even the behavior of these crickets has a physiological distinctiveness, for they appear very reclusive, living in holes and burrows under the clods. Later, when the great midsummer broods appear, this continuous trilling form disappears, and the typical chirping form replaces it.

I have likewise found a most marked departure in the tiny bush cricket, *Anaxipha exigua.* An early physiological race appearing in May and June, and confined entirely to dead ground—débris of the low, wet, grassy bogs of meadows and swamps—has the habit of prolonged trilling. The great typical assemblage which appears in August clings to the higher, drier zone of upland herb and shrub, and produces a thin, shrill, intermittent chirp, usually by the single wing stroke I have previously described. Morphologically the classificationist can find nothing to distinguish these physiological forms from the typical species assemblage. Yet they exist, because nature

eternally works in the direction of physiological distinctiveness as well as in that of morphological distinctiveness.

Other field naturalists, including Fulton in his studies of the *Oecanthus* group, have noted these facile physiological variations. Why one group should become so readily standardized within its environment as to stridulate with a vernacular of its own is difficult to see. It is true that the time relations more than anything else appear to be involved in the dissimilar habits of stridulation. The chirp of the cricket is merely a frequent sectioning of the continuous trill into more or less uniform patterns, and the single-stroke note is but an extreme slowing down of the rapid and continuous wing movement which produces the quavering trill. What leads to the final, rigid adoption of these measures and intervals is not always clear. One may say, however, that the less one knows of life the simpler it appears in its manifestations, and the more one concentrates his attentions upon its actualities and potentialities in the finer magnitudes of its expressions the more complex do its correlations appear.

With much confidence we speak of the vernaculars of men and claim to recognize with no great difficulty the New Englander from the South Carolinian or the Kansan. There is reason to believe that crickets and katydids have their disconcerting regional vernaculars and provincialisms as well. Snodgrass has noted this peculiarity in the case of the true katydid, *Pterophylla camellifolia*, and says: "It is very noticeable that the song of the katydids about Washington is much less harsh and grating in tone than is that of the New Englanders." I can fully agree with Snodgrass; peculiar intonations unquestionably exist, constituting a definite vernacular. I have observed the same distinctiveness in the singing of other katydids, including the oblong-winged katydid, *Amblycorypha oblongifolia*, there being an appreciable difference between the tones of the New England musicians and those of the Washington musicians of this species. Somehow the two groups inflect differently, or those of one group dwell more upon their notes, or rasp more or less energetically, and that is all we know about it. These distinctions are moods and modes of inherent physiology and environment of which we know little. A vernacular, as we have seen, may exist in widely separated localities, or almost interblend with others in the same locality. It is probable that these isolations of speech or language among insects have much in common with the localized vernaculars and provincialisms of men, eternally becoming emphasized in valley and plain over all the earth. As the matter stands, profound differences of stridulation may be found with no noticeable modification in the morphological facies, or profound changes in color, etc., may suddenly arise with no evident change in the method of stridulation. A year ago I found a decidedly

black or melanistic individual of the snowy-tree cricket chirping in the usual manner near Washington, D. C. Thus the story of life goes on and on as it pleases, with eternal admonitions to the scientist to beware of his theories and classifications, for they are transient and unreal.

THE HEARING ORGANS OF INSECTS

Much has been written concerning the hearing organs of insects, but I confess to grave feelings of doubt as to the correctness of many of our views. That all insect instrumentalists hear their own sounds I have not the slightest doubt, for I have positive evidence that their hearing is exceedingly acute. I had at one time a female bush katydid, *Phaneroptera curvicauda*, in captivity in my bedroom, which would lisp out responses to my own lisping mimicry as often as I cared to stimulate it. In tests with this katydid I stepped away slowly the entire length of the room, lisping so low as barely to hear it myself, and yet it heard and responded promptly. We are told that the ears or tympana of the grasshoppers, *Acrididae*, are on the first segment of the abdomen, near the insertion of the wings. The katydids and crickets, we are informed, have auditory structures on the tibia of the forelegs, near the knee, on one or both sides. Noticeable depressions and tympanal membranes are situated here, connecting with internal air chambers and sensory specializations involving the nerve structures. There are implications which are not entirely clear, however, for, as mentioned by Snodgrass, the legs of the honeybee show somewhat analogous structures, but without the tympanal membrane. Of more puzzling import in this connection, the tiny musical crickets, *Falcicula hebardi*, appear not to possess the usual tibial auditory structures of crickets, and we wonder how they hear their own sounds, musicians that they are. There is much to be learned concerning the senses and sense impressions of insects, and we, in our enormously greater magnitudes of body and mind and, let me say, emphasized egotisms, must ever find it a stupendous task, perhaps insurmountable, to see and think and feel truthfully in terms of the insects themselves.

THE MUSICAL MOODS OF THE CRICKETS AND KATYDIDS

Just as we have in the human race people who are given to whistling, humming, or singing, almost with exasperating persistency, so we find our insect musician characterized by similar proclivities. The moods of some insects incline them to an almost perpetual self-expression until death silences them. Some of the cone-headed katydids, as for instance the robust conehead, *Neoconocephalus robustus*, become mere humming machines all their days and nights, from August, when they become adults, until frost kills them. Their

muscular energy is prodigious, for they must produce some thousands of strokes per minute of the scraper over the file vein, for hours, days, weeks, until death overtakes them. These powerful katydids probably rasp their file veins with their scrapers from thirty to fifty million times in the course of a season, in some weird, incomprehensible, mood of consciousness and self-expression. Sexual allurements alone do not account for this tremendous expenditure of nervous and muscular energy, but perchance some inherent, pervasive mood that makes all things move and spin eternally in a round of restless play, whether it be electrons, planets, or what not, in the physical universe. If this is the extreme of intense organic song energy we find the snowy tree cricket breaking it up into periods of rest, like the incessantly recurring beats of our own hearts, with alternations of rest and work. The very extreme of reduced song energy appears to have been attained by such katydids as the Phaneropteras, which may deliver only a few strokes of the scraper upon the file vein in a day, in the most indifferent and haphazard manner. It is a mystery how the sound-making devices have arisen at all, even on those surfaces where, owing to the proximity of their frictional instruments, they should be expected to arise. It is a mystery how the moods of stridulation are so fixed and innate as to make each cricket and katydid know intuitively the distinctive notes of its own species. It would appear that both physical and psychic elements enter into the matter. Some of the grasshoppers of the genus *Melanoplus*, which have no stridulatory organs, nevertheless appear to have the mood for stridulation, for they have been observed to go in some blind way through the usual stridulatory movements of other grasshoppers. On the other hand, one of our bush crickets, *Hapithus agitator*, has the structures present but appears little inclined to stridulation. Rarely does this cricket stridulate, and rarely, it would seem, does it even want to stridulate. At least it is more sluggish in this reluctant behavior than any other cricket I have ever observed. I have a feeling that the mood for stridulation is waning in this cricket, just as we find birds little inclined to fly, or birds with wings diminished in size. Life is a matter of impulses, which may be strong or weak, regardless of the consciousness of the individual. I see no reason why crickets, from some weird, inherent cause, should not become as averse to stridulation as some birds appear to have become averse to flying. These are the moods of life which defy explanation, but they are the moods, so to speak, of atoms, molecules, proteins, radium, and what you will in the universe—change upward, change downward, but never constancy or fixity in anything.

APPRECIATION OF INSECT SOUNDS

Humanity is in its babyhood when its age is compared with the ancient lineage of the insects. It is possible that musical insects were fiddling out songs to their own race in the great waving jungles of Carboniferous ferns, millions of years before man's embryonic beginnings were even indicated.

The genealogy of it all is an eternal puzzle. It would seem that the earliest insect musicians were among the *Neuroptera*, but somehow they did not remain musically inclined and the *Orthoptera* took up the tunèd lyre in dead earnest. However this may be, men in all stages from savage to civilized have at times been impressed by the sounds of insects. We are told that the natives of Uganda kept *Gryllotalpa africana* and *Acheta bimaculata* in warm ovens, to induce soothing sleep with their music and to be eaten if need be.

In Italy the crickets have been greatly venerated for their music and have been kept in pretty painted cages to be sold on the streets by peddlers. The insect was supposed to bring good luck or misfortune for the coming year, depending upon its proclivities as a musician. The Japanese, perhaps more than any other peoples, have become genuinely imbued with a true love of insect music. Their land appears to be particularly rich in large, musical, insect forms, many having especially fine powers of musical expression. The Japanese are an ancient people in comparison with the youthful peoples of America or of Europe. Centuries ago, when our great epic poem Beowulf was being repeated from mouth to mouth, they had somehow evolved such a fondness for their musical insects that they were in that ancient day given to countryside pilgrimages to hear them and feel the thrill of poetic associations which their "music" inspired. In Japan at the present time it is a practice to cage them in attractive bamboo cages to hear their music, and they figure in the trade of the cities as do caged song birds in our own land. There is something rather distinctive in this Japanese love of insect music; to say the least, it attests an intensive love of nature which we as Americans rarely evince except in occasional individuals— a Thoreau, a Burroughs, an F. Schuyler Mathews, a Scudder.

We Americans are too busy, too hurried, too mechanized in our moods, to stop long enough to hear what this cricket or that katydid says. Ah! if we can not hear the bird or cricket or katydid itself, we are surely going to ignore the poem which portrays it as some one else heard it. To-day we are a hurried, worried people. To the majority delving into nature studies, into poetry, art, the finer literature, is not a materially gainful pastime. Many a time have I been asked "What good are crickets and katydids? Why bother about them?" That is typical of the average American logic, but there is more to life than measuring every mood in terms of financial

reward. The cultures of men are rarely of a remunerative order, but their rôle is as vital and as urgent in the disciplines and stimulations of a happy and appreciative life as the mere needs of a roof, something to eat, and something to wear.

STUDYING THE STRIDULATIONS OF THE MUSICAL INSECTS

The study of the musical moods and behaviors of the insect-instrumentalists of the earth is no small matter. Musical insects are world-wide in their distribution, and few have been intensively studied, even in our own country. It is a fascinating subject, nevertheless. Insects have taken far more universally to sound production than to light production. Strangely enough, some groups of beetles have in a most spectacular way become adepts at light production, just as the Orthoptera have become the great sound makers of the earth. Somehow, there are weird analogies here, for the various fireflies have learned to handle light with all the moods and modes and facilities with which the musical insects handle sound. They make it as a continuous glow, they flash it intermittently, in certain social moods they synchronize their flashings just as some of our tree crickets synchronize their chirpings.

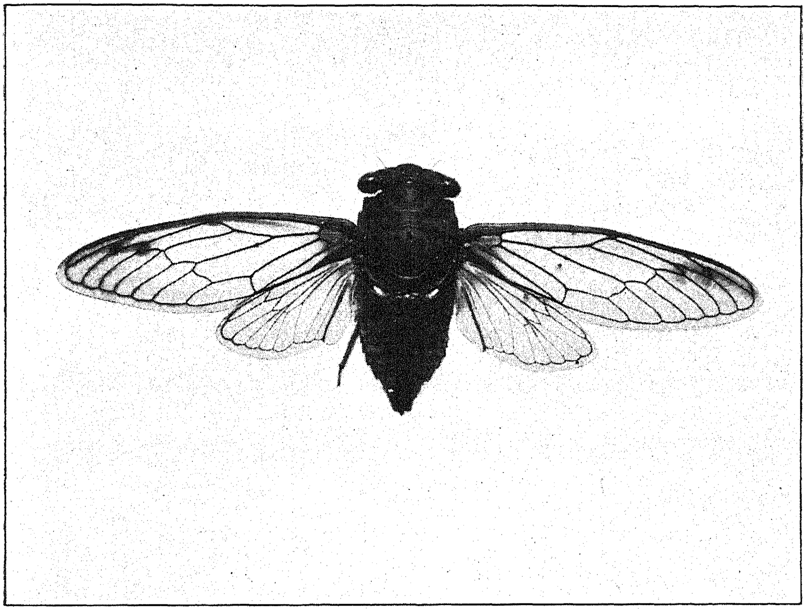
There are wonderful possibilities ahead for the student of insect sounds. There is the problem of making in some manner permanent records of the sounds of the various insects. This appears never to have been attempted. There is the problem of making motion pictures of the insects during their musical activities. To do this would be particularly desirable, since an accurate analysis of all their wing movements could be determined, and the actual technique of the musical strokes revealed in detail. It is going to be no simple matter, however, to photograph the more wary nocturnal species which do their singing mainly in the dark.

It is not sufficient merely to describe the impressions of the note made by a particular insect. If possible, the technique of its production should be carefully observed and recorded, because of the vast and fundamental differences of behavior. The careful and observant nature lover has a most fascinating field before him in all parts of the world. In our own country the habits, stridulations, technique, and other peculiarities of the forms west of the Mississippi River merit much attention, for many fine katydids dwell there, playing weird tunes upon their organic xylophones. Still photographs at least could be made of the insects in life, and are much needed, especially if they can be made of natural size.

The story of our insect musicians and their distinctive moods has as yet been touched by only a few observers. I am convinced, however, that if it were thoroughly worked out for all the musical insects of the world we should uncover variations of technique and

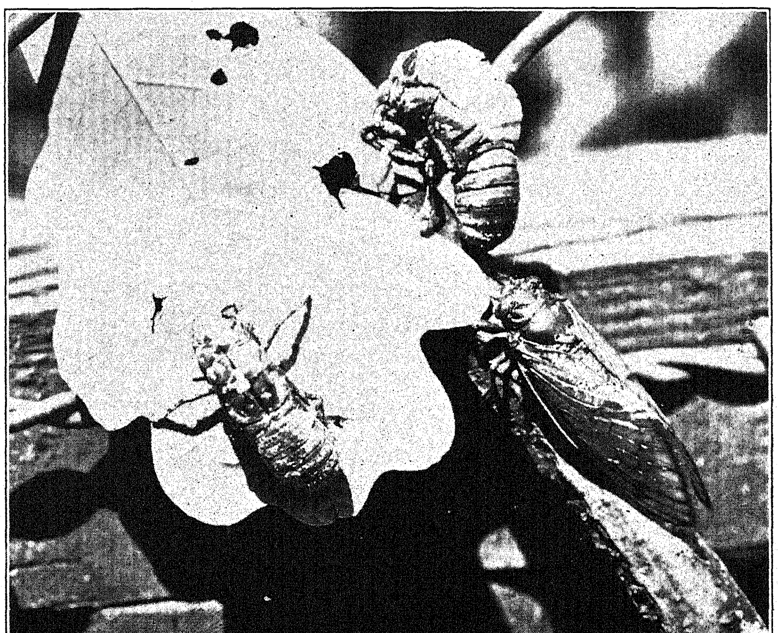
musical specializations as remarkable as those I have shown to exist with our own larger angular-winged katydid, *Microcentrum rhombifolium.*

This specialized interest may seem very remote from our practical affairs of a mechanized age, but the basis of all pure science is healthful curiosity; and truth, whatever its nature or revelations, is worthy of record in the archives of men. The singing cricket on my hearth may not add to the contents of my pocketbook, but at times it affords an indefinable inspiration and poetry that reveals new beauties of living, of expression, and of association in the universe. I am better, broader, wiser, happier for having heard the crickets and katydids, for somehow there are points of kinship in our lives, even though our magnitudes and rôles of living seem so far apart.



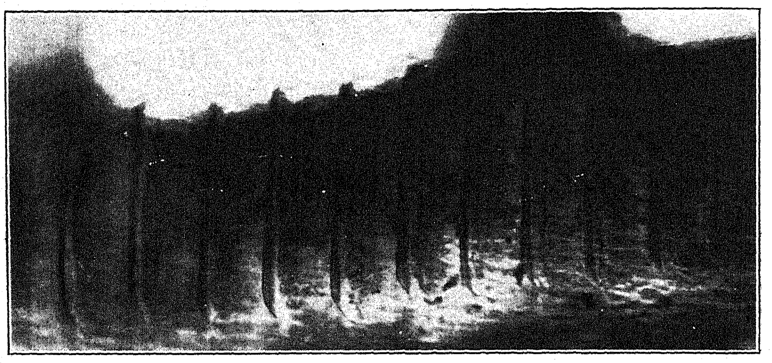
1. CICADA, TIBICEN LYRICEN, MALE

About natural size. The so-called harvest fly. Its "song" is a loud ringing z-ing-ing-ing produced within specialized body cavities by the vibrations of very thin, chitinous plates. (By permission of Country Gentleman. Photograph by H. A. Allard)



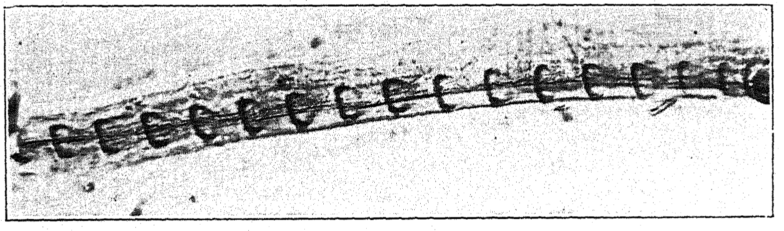
2. THE 17-YEAR CICADA, TIBICEN SEPTENDECIM

About natural size. At left empty pupal shell; at top emerging adult which has died in birth; adult drying and gaining strength. When these interesting cicadas appear at their appointed time, the mid June days are filled with their low murmurous sounds. (Photograph by H. A. Allard)



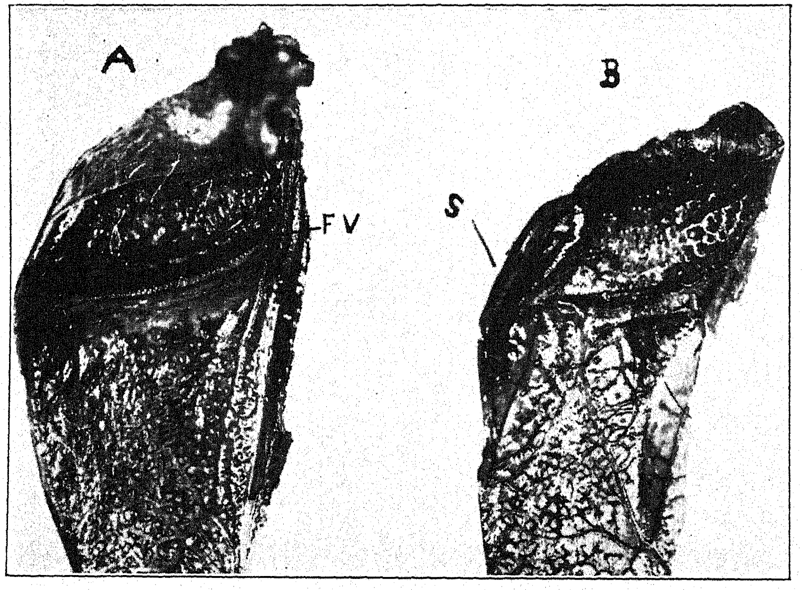
1. TEETH OF FILE VEINS OF OBLONG-WINGED KATYDID, AMBLYCORYPHA OBLONGIFOLIA

Magnified about one hundred and eighty-five times. The teeth are very heavy and broad in comparison with the teeth on a tree cricket's file vein. (Photograph by Ernst Artschwager)



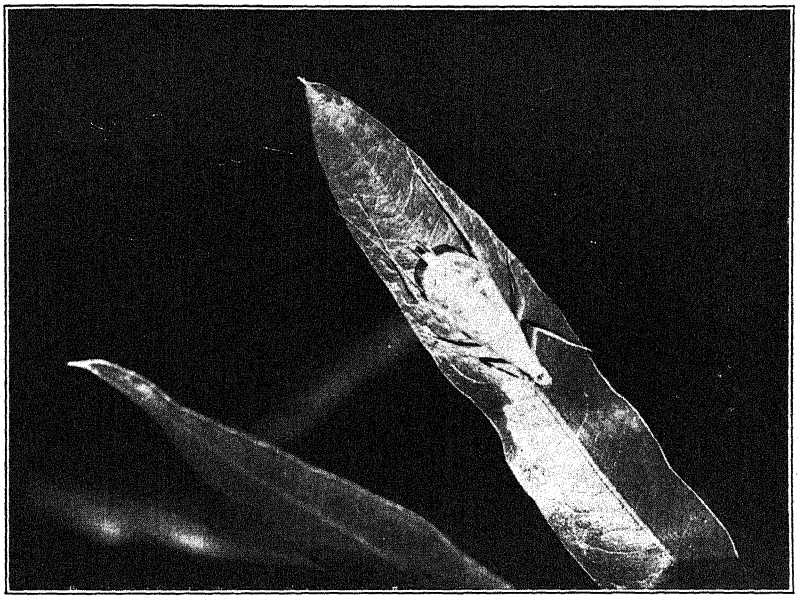
2. TEETH OF FILE VEIN OF TREE CRICKET, OECANTHUS NIGRICORNIS

Magnified about one hundred and eighty-five times. (Photograph by Ernst Artschwager)



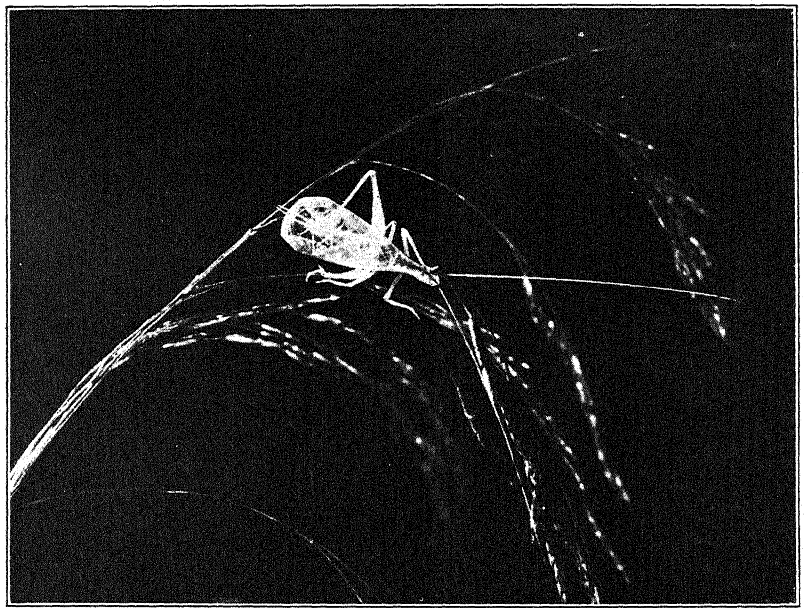
3. MUSICAL ORGANS OF LARGER ANGULAR-WINGED KATYDID, MICROCENTRUM RHOMBIFOLIUM, MALE

A, file vein, FV, on under surface of upper tegmen, showing teeth; B, scraper, a chitinous ridge at S situated on the upper edge of the lower tegmen. Magnified about ten times. (From Scientific Monthly, July, 1928)



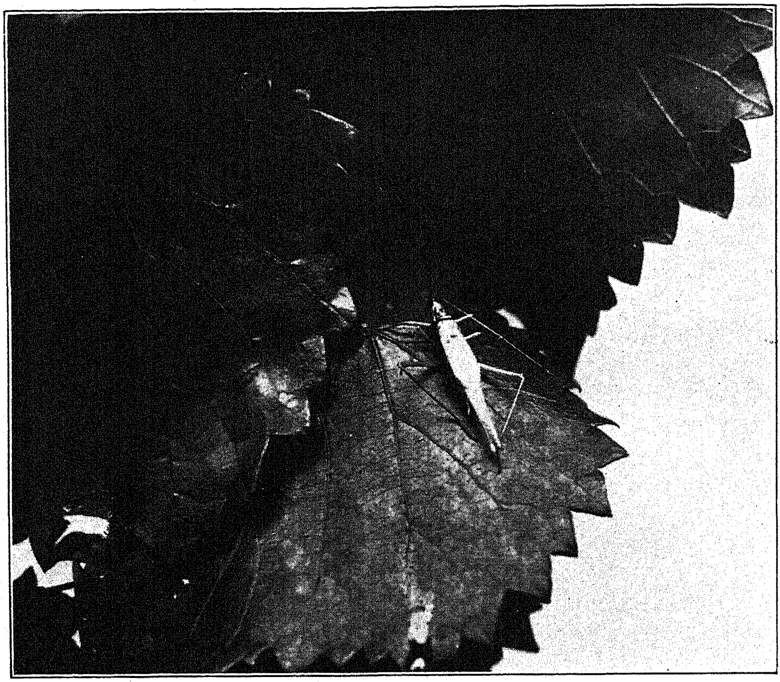
1. SNOWY TREE CRICKET, OECANTHUS NIVEUS, MALE

Somewhat larger than natural size. Its rhythmic chirps are heard on August nights. (Photograph by H. A. Allard)



2. BROAD-WINGED TREE CRICKET, OECATHUS LATIPENNIS, MALE

Somewhat larger than natural size. Its notes are a steady monotone. (Photograph by H. A. Allard)

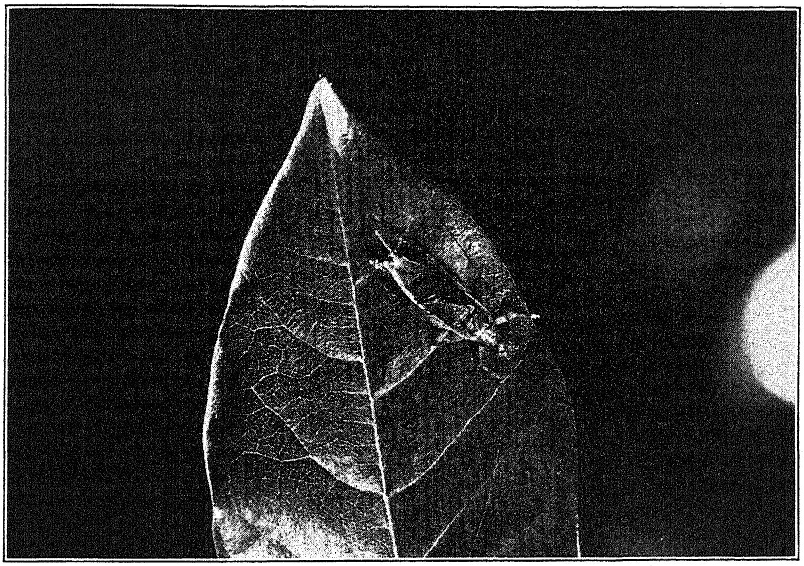


1. TWO-SPOTTED TREE CRICKET, NEOXABEA BIPUNCTATA, MALE

About natural size. Its notes are weird and droning, and without measured rhythm. (Photograph by H. A. Allard)

2. FOUR-SPOTTED TREE CRICKET, OECANTHUS NIGRICORNIS QUADRIPUNCTATUS, MALE

About natural size. These trilling crickets hide among the goldenrods and asters. (Permission of Country Gentleman. Photograph by H. A. Allard)

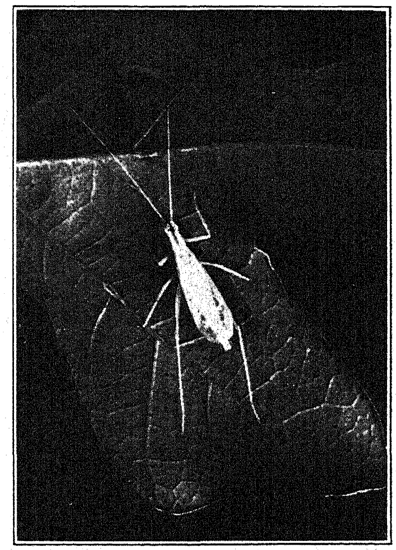


1. JUMPING TREE CRICKET, OROCHARIS SALTATOR, MALE

About natural size. Clear, bell-like, vibrant is the autumnal music of their wings. (Photograph by H. A. Allard)

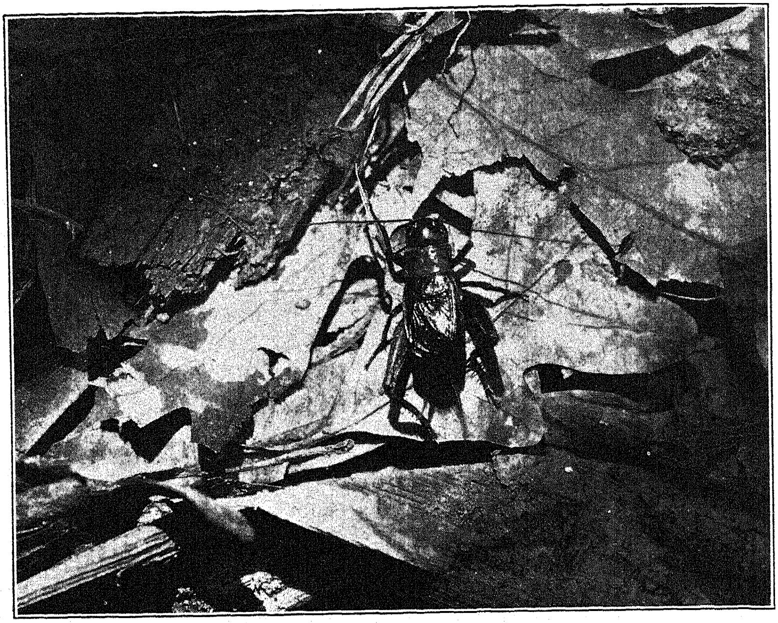
2. NARROW-WINGED TREE CRICKET, OECANTHUS ANGUSTIPENNIS, MALE

About natural size. Notes rather sad and wailing. (Photograph by H. A. Allard)



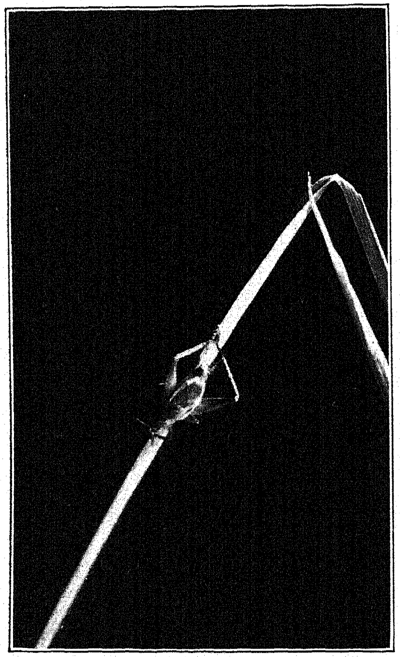
3. RED-HEADED TREE CRICKET, PHYLLOSCYRTUS PULCHELLUS, MALE

About natural size. This tiny triller has a brilliant crimson head and shoulders. (Photograph by H. A. Allard)



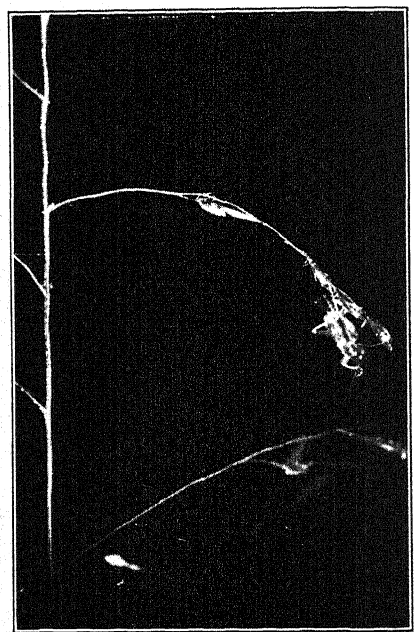
1. COMMON FIELD CRICKET, GRYLLUS ASSIMILIS, MALE

About natural size. (Photograph by H. A. Allard)



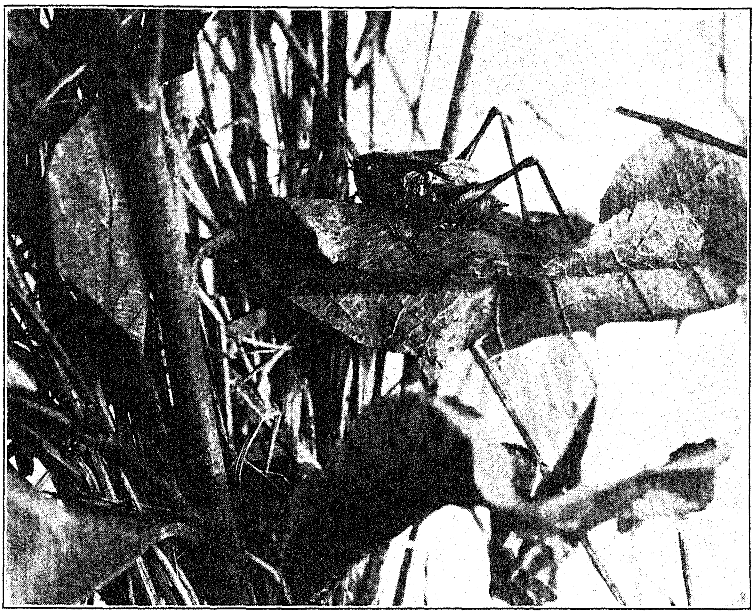
2. RESTLESS BUSH CRICKET, HAPITHUS AGITATOR, MALE

About natural size. A very indifferent musician, as if too lazy to trill. (Photograph by H. A. Allard)



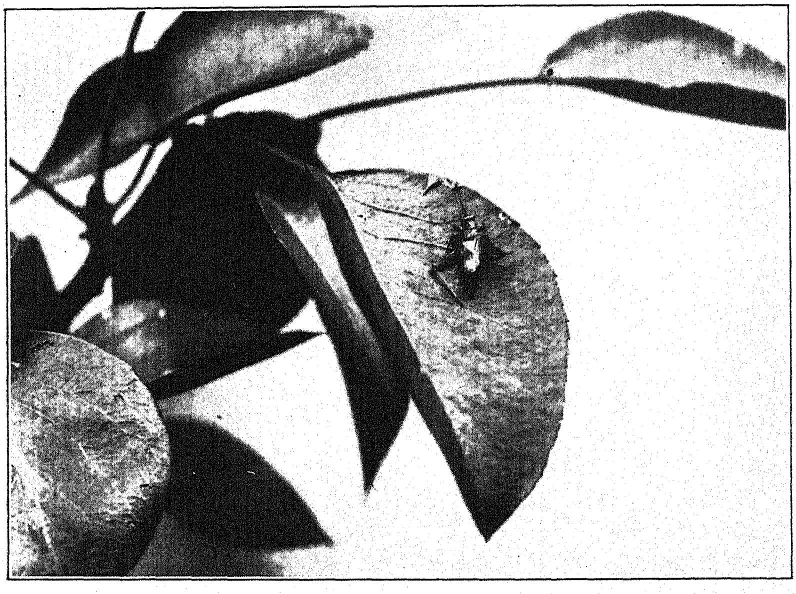
3. TINY BUSH CRICKET, ANAXIPHA EXIGUA

About natural size. It produces veritable points of smooth sound with single wing strokes. (Photograph by H. A. Allard)



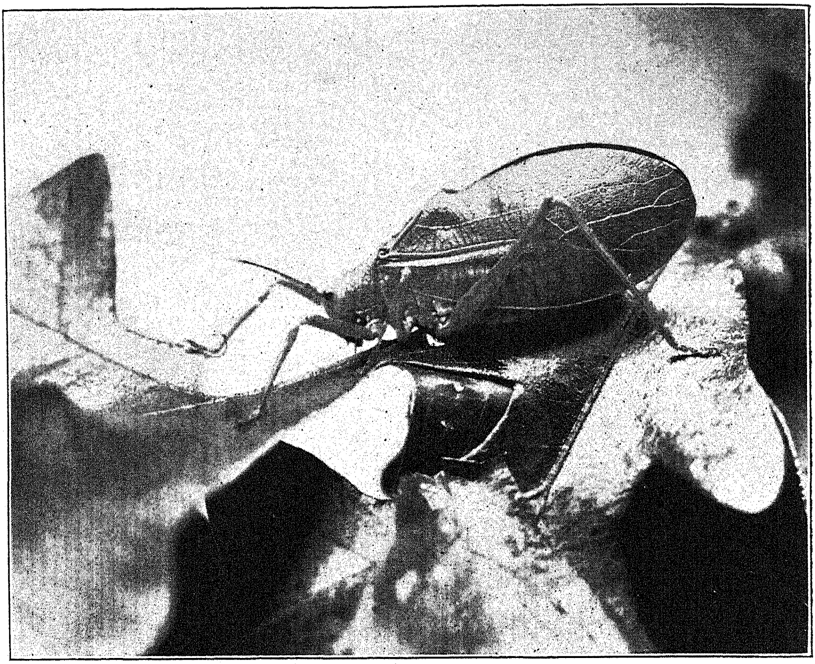
1. SHIELD BEARER, ATLANTICUS TESTACEUS

About natural size. A queer short-winged katydid of the low ground cover. Its wings are just long enough to be used for musical purposes. (Photograph by H. A. Allard)



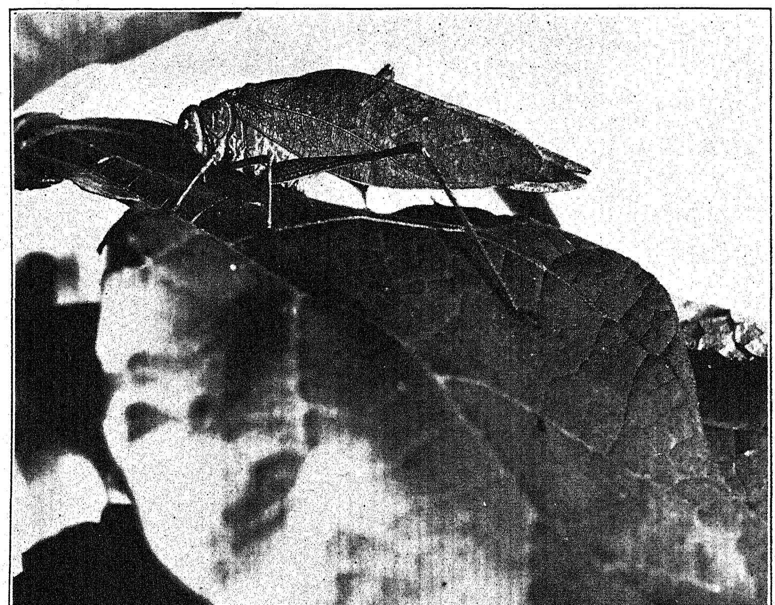
2. TINY TREE CRICKET, CYRTOXIPHA GUNDLACHI COLUMBIANA

About natural size. Its notes are thin, high-pitched chirps. (Photograph by H. A. Allard)



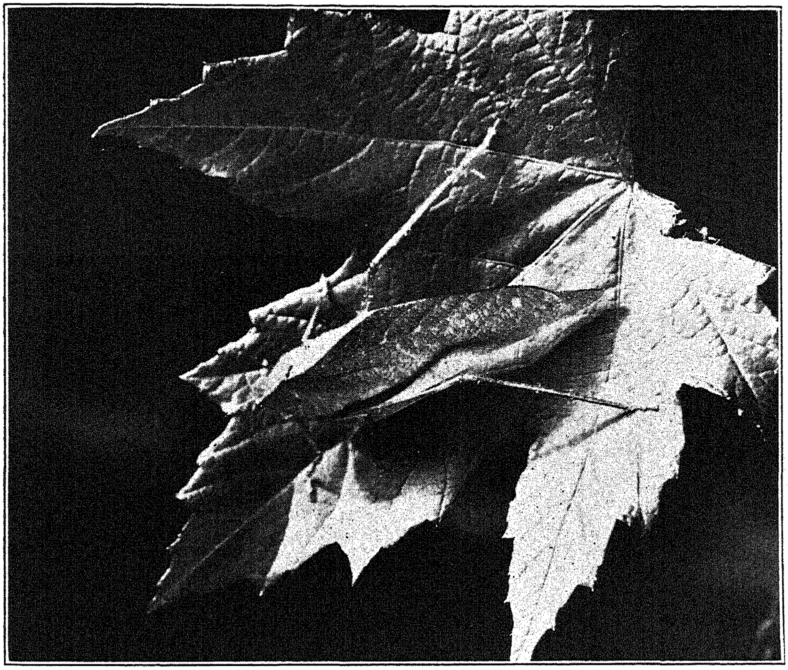
1. THE TRUE KATYDID, PTEROPHYLLA CAMELLIFOLIA, MALE

Somewhat larger than natural size. The katydid of poetry, voicing the spirit of country life and serenity. (Permission of Country Life. Photograph by H. A. Allard)



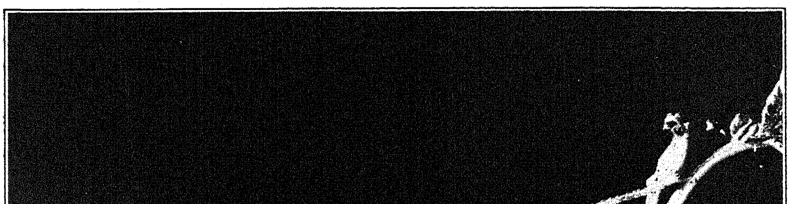
2. LARGER ANGULAR-WINGED KATYDID, MICROCENTRUM RHOMBIFOLIUM, MALE

About natural size. Leafy-winged, he clicks off notes from the single teeth of his file vein. (Photograph by H. A. Allard)



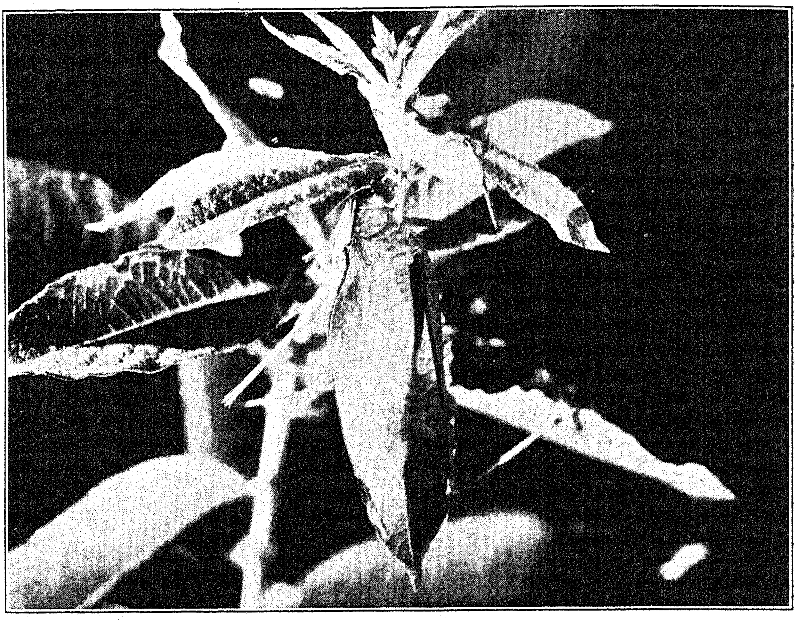
1. SMALLER ANGULAR-WINGED KATYDID, MICROCENTRUM RETINERVE, MALE

About natural size. His wings, too, are leaflike. A rare singer of the forest crown. (Photograph by H. A. Allard)



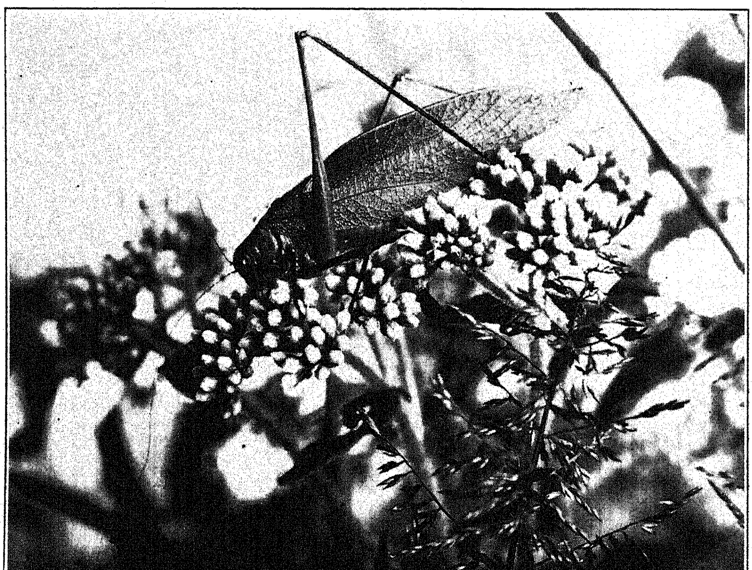
2. THE LARGER ANGULAR-WINGED KATYDID, MICROCENTRUM RHOMBIFOLIUM, MALE

About natural size. His wings are his musical organs, his camouflage, and the roof to his body in heavy rains, beneath which he holds his antennæ. (Photograph by H. A. Allard)



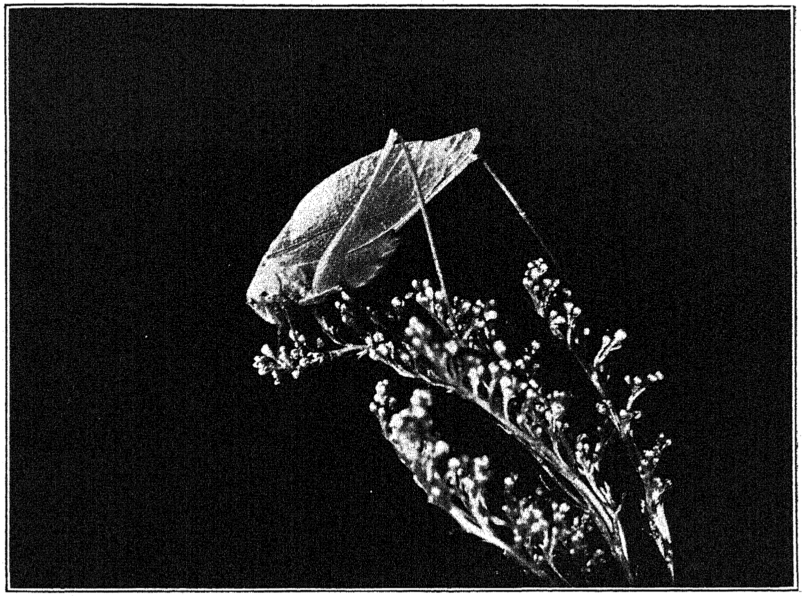
1. OBLONG-WINGED KATYDID, AMBLYCORYPHA OBLONGIFOLIA, MALE

About natural size. Here is a perfect instance of camouflage, the insect leaf, so to speak, and the plant leaf being almost indistinguishable. (Photograph by H. A. Allard)



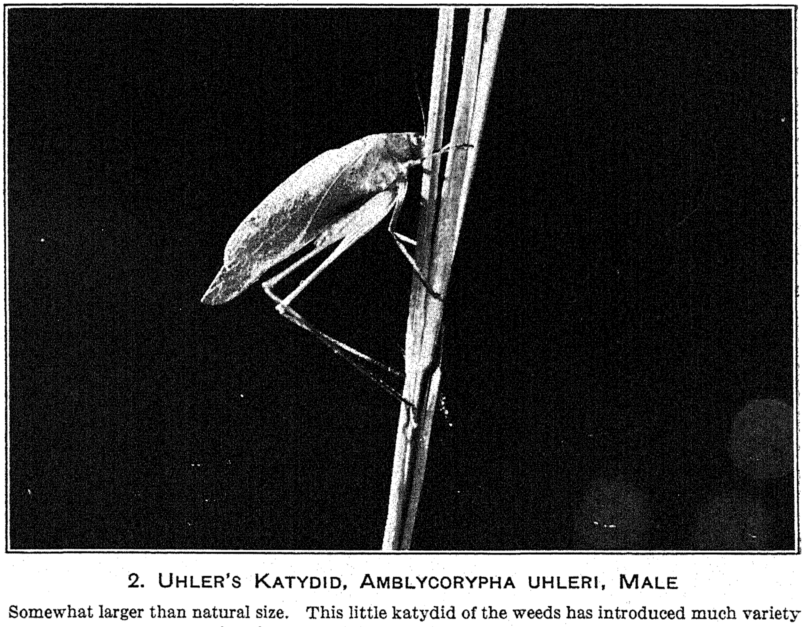
2. OBLONG-WINGED KATYDID, AMBLYCORYPHA OBLONGIFOLIA, MALE

About natural size. Its notes are rasping and leisurely, it-z-z-zic—it-z-z-zic. (By permission of Country Life. Photograph by H. A. Allard)



1. ROUND-WINGED KATYDID, AMBLYCORYPHA ROTUNDIFOLIA, MALE

Somewhat larger than natural size. A soft lisping song is its only music. (Photograph by H. A. Allard)

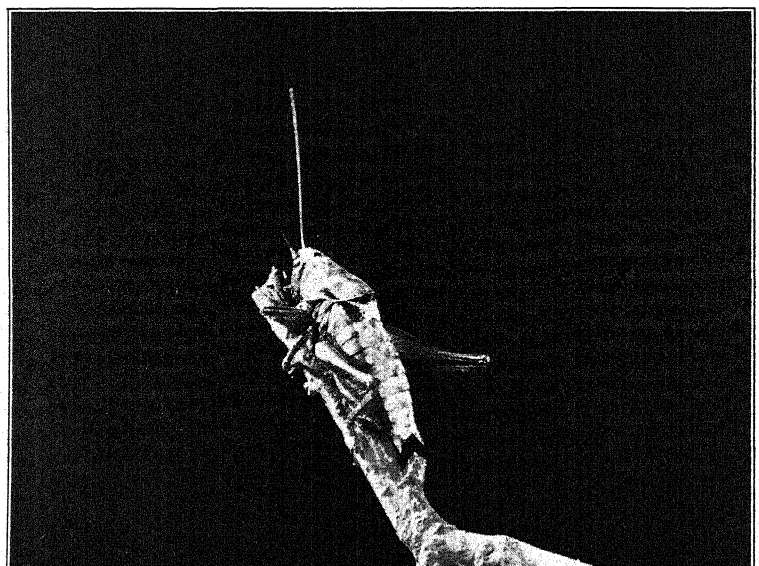


2. UHLER'S KATYDID, AMBLYCORYPHA UHLERI, MALE

Somewhat larger than natural size. This little katydid of the weeds has introduced much variety into its song. (Photograph by H. A. Allard)

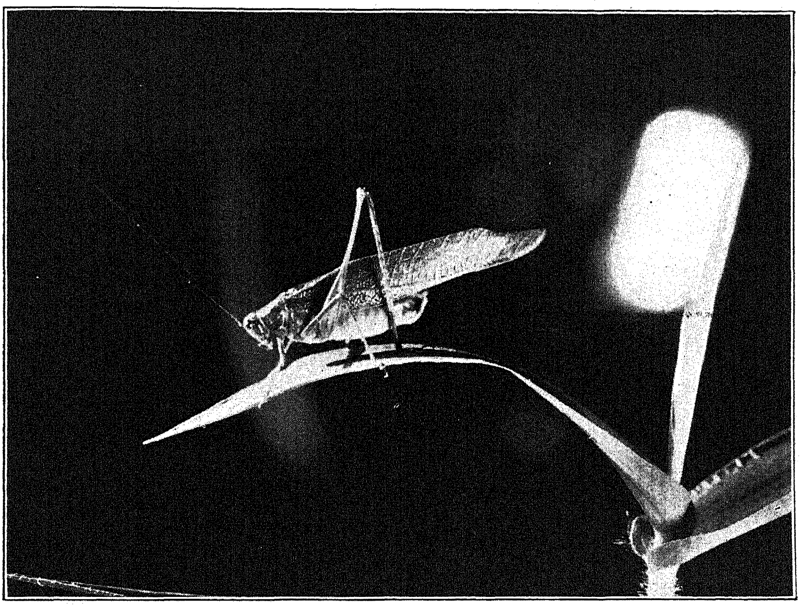
1. BRUNER'S CONE-HEADED KATYDID, NEOCONOCEPHALUS EXILISCANORUS, MALE

About natural size. One of our finest coneheads, and one that sometimes rasps in unison with its fellows. (By permission of Country Life. Photograph by H. A. Allard)



2. DAVIS'S SHIELD BEARER, ATLANTICUS DAVISI, MALE

Somewhat larger than natural size. The earliest katydid to appear in the Washington region. Notes long and lisping and of irregular duration. (Photograph by H. A. Allard)

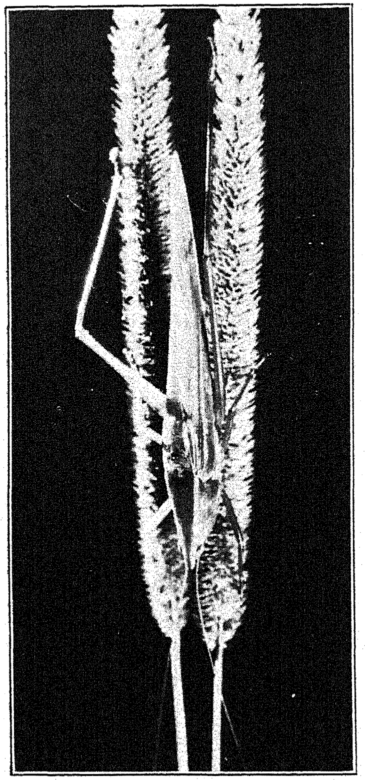


1. FORK-TAILED KATYDID, PHANEROPTERA FURCATA, MALE

About natural size. A trim green insect of the herbage and shrubs, with keen, incisive notes sparsely delivered. (Photograph by H. A. Allard)

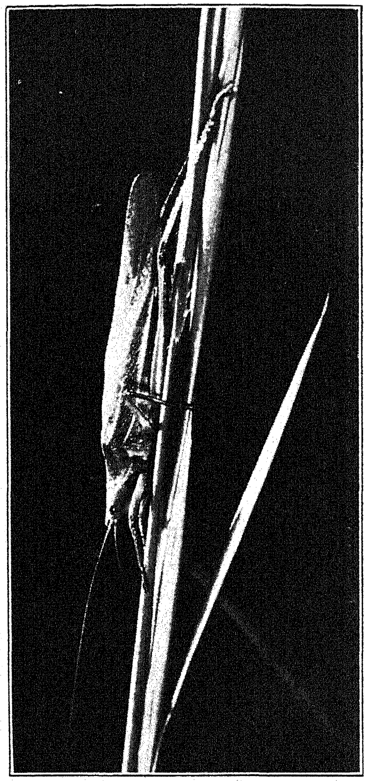
2. CURVE-TAILED KATYDID, PHANEROPTERA CURVICAUDA, MALE

About natural size. A loud and incisive zeep is the usual call of this katydid. (Photograph by H. A. Allard)



1. ROBUST CONE-HEADED KATYDID, NEOCONOCEPHALUS ROBUSTUS, MALE

About natural size. This katydid hums a high-speed song with the ceaseless drone of a machine. (Photograph by H. A. Allard)



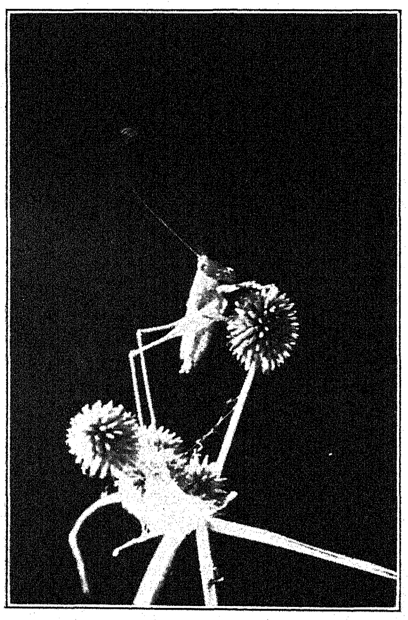
2. THE ROUND-TIPPED CONE-HEADED KATYDID, NEOCONOCEPHALUS RETUSUS, MALE

About natural size. Its note is a dry, snappy continuous sound in the weeds and grass. (Photograph by H. A. Allard)

3. SLENDER MEADOW KATYDID, CONOCEPHALUS FASCIATUS, MALE

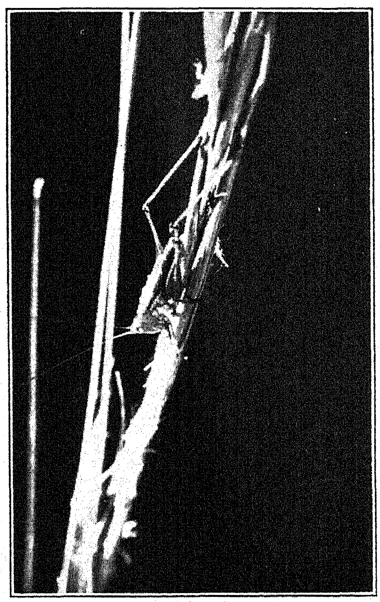
1. PINE-TREE KATYDID, ORCHELIMUM MINOR, MALE

About natural size. This katydid has assumed the deep green of the pine trees on which it dwells. (By permission of Country Life. Photograph by H. A. Allard)



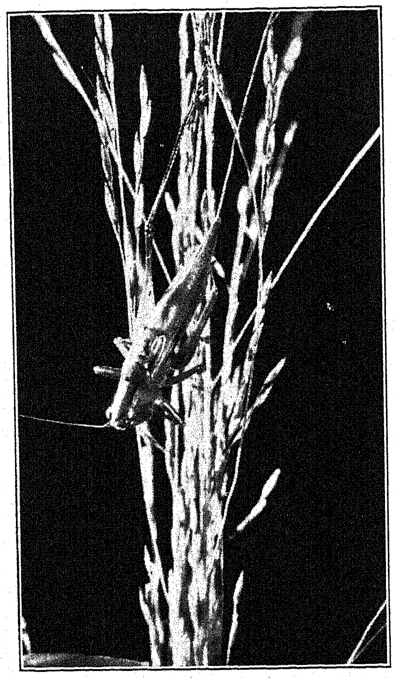
2. WOODLAND KATYDID, CONOCEPHALUS NEMORALIS, MALE

About natural size. It is shown here cleaning its antennæ by running them through its mouth parts outward toward the tip. (Pho-



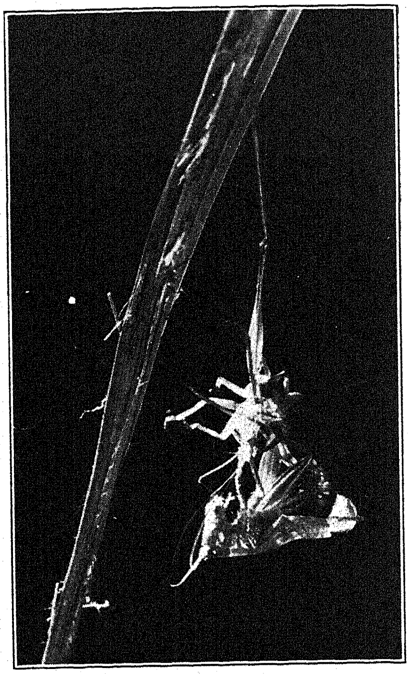
3. STRAIGHT-LANCED MEADOW KATYDID, CONOCEPHALUS STRICTUS, MALE

About natural size. A tiny katydid of the grasses and herbage. (Photograph by H. A. Allard)



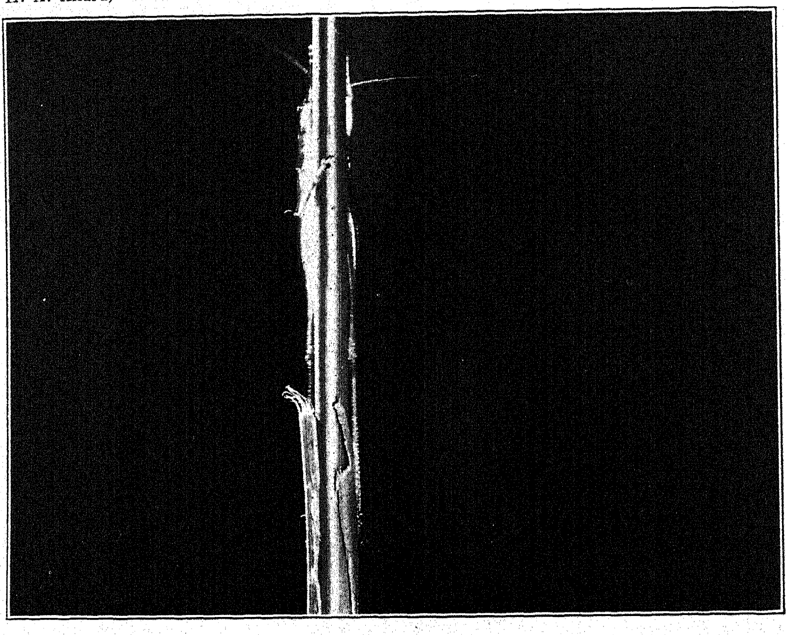
1. COMMON MEADOW KATYDID, ORCHELIMUM VULGARE, MALE

About natural size. An eternal lisping in the roadside weeds in late summer is the music of the larger meadow katydid. (Photograph by H. A. Allard)



2. COMMON MEADOW KATYDID, ORCHELIMUM VULGARE, MALE

About natural size. Hanging from his old skin, having just emerged a full-fledged musical creature at the fifth molt. (Photograph by H. A. Allard)



3. COMMON MEADOW KATYDID, ORCHELIMUM VULGARE, MALE

THE NEANDERTHAL PHASE OF MAN[1]

By Aleš Hrdlička

[With four plates]

I. INTRODUCTORY REMARKS

In choosing my subject for the Huxley lecture, it was only natural to reflect what he, in whose honor the lecture is given, would have chosen; and I felt that with his interest, keen mind, and extensive knowledge he would doubtless have preferred some of the most unsettled and difficult problems of man's antiquity and evolution. And he could hardly find to-day one offering more difficulties, and the clearing of which is of more importance to science, than that of Neanderthal man; a subject which, moreover, was one of his first concerns.

Huxley, as early as 1863, published, as one of his essays on the Evidence as to Man's Place in Nature (8vo, London), under the subtitle On Some Fossil Remains of Man (pp. 118–159), a noteworthy discussion on the Neanderthal skull. In this essay, at that early date, and in opposition to the authority of Rudolf Virchow, Huxley recognized that there was no reason for regarding the skull as pathological; that it unquestionably represented typical race characters; and that this race was inherently related to man of to-day.

Since Huxley, the Neanderthal skull and Neanderthal man have been written about extensively, but often with but little originality. New finds belonging to the period have become numerous—almost more numerous than legitimate new thoughts. To-day it is no more the question of a single skull, but of a large and important section of man's antiquity, documented ever more geologically, paleontologically, and anthropologically. But the distressing part is that the more there is the less we seem to know what to do with it. Speculation there has been indeed enough, but the bulk of it so far has led not into the sunlight, but rather into a dark, blind alley from which there appears to be no exit.

---

[1] The Huxley Memorial Lecture for 1927. Reprinted by permission, with minor alterations by the author, from the Journal of the Royal Anthropological Institute, Vol. LVII, July–December, 1927.

The generalized present doctrine about Neanderthal man may best be seen from the following brief quotations, taken from four of the most recent and representative authors, one a paleontologist, one an anatomist, and two prehistorians:

Marcellin Boule (Fossil Men, 1923, pp. 242–243):

> *Homo neanderthalensis* is an archaic species of man. It was abruptly followed by the Aurignacians, "who differed from the Mousterians as much in their superior cultures as in the superiority or diversity of their physical characters."

M. C. Burkitt (Prehistory, 1921, p. 90):

> The race who made this culture (Mousterian) was of a low type known as the Neanderthal race. This appears to have been a throwback in the line of evolution of mankind, and this retrograde sport seems to have had no successor.

George Grant MacCurdy (Human Origins, 1924, Vol. I, pp. 209–210):

> During ages long subsequent to the time when the races of Piltdown and Heidelberg lived, there spread over the greater part of Europe the primitive Neanderthal race, of course mental and physical fiber. . . . This race contributed nothing, in fact, save utilitarian artifacts, the so-called Mousterian industry. . . . The Aurignacians were a "new race," which supplanted completely the archaic Neanderthal race of Mousterian times.

Sir Arthur Keith (The Antiquity of Man, Vol. I, pp. 198–199):

> The most marvelous aspect of the problem raised by the recognition of Neanderthal man as a distinct type is his apparently sudden disappearance. He is replaced, with the dawn of the Aurignacian period, by men of the same type as now occupy Europe. . . . A more virile form extinguished him. . . . He was not an ancestor of ours, but a distant cousin.

All these opinions can probably be traced to the authoritative notions arrived at during the earlier years of this century, on material less ample than at present, by one of the foremost students of Neanderthal man, Gustav Schwalbe.

There were, and are, however, also other views. From Huxley and Busk to Karl Pearson; from Fraipont and Lohest, Houzé, Kollman, and Sergi to Stolyhwo, Gorjanović-Kramberger, and, most recently, Weidenreich, there have been expressed opinions that Neanderthal man was not a different species, and that he did not completely die out, but became gradually transformed into later human forms, from which in turn developed man of to-day.

The problem of Neanderthal man, as it now exists, presents the following uncertainties: It is not yet properly known just where, when, and how he began, and how far eventually he extended geographically; it is not yet definitely known just who he was and what were his phylogenetic relations to the man that succeeded him; and it is not known plainly just why and how he ended, and whether or

not he left any progeny. Besides which there are still but more or less vague notions regarding the exact length of his period, his average physique, his variations and subraces, the reasons for his relatively large brain, his changes in evolutionary direction. And there are other uncertainties. It thus appears that, notwithstanding his already numerous collected remains, Neanderthal man is still far from being satisfactorily known to us taxonomically, chronologically, and anthropologically.

This state of uncertainties, and of paralyzing notions, concerning one of the main early phases of humanity, is a serious obstacle to further progress and deserves all possible attention, even if, without further material, it may be possible to do little more than bring into the subject a greater degree of order and comprehensiveness; to point out here and there facts that have not been sufficiently weighed; and to call attention to some of the inconsistencies in the prevalent assumptions.

The presentation will be as far as possible impersonal; and I wish to acknowledge my deep indebtedness for many of the data to the authors given in the references, as well as to those who in the past, and again during the weeks just passed, have facilitated for me the study of original sites and materials.

II. NEANDERTHAL MAN

DEFINITION

The only workable definition of Neanderthal man and period seems to be, for the time being, *the man and period of the Mousterian culture*. An approach to a somatological definition would be feasible, but might for the present be rather prejudicial.

GEOGRAPHICAL EXTENT

The territory already known to have been occupied by Neanderthal man was collectively a very large one. It includes, roughly, all Europe south of a line drawn from southern England to the northern limits of Belgium and thence, with a moderate curve northward over Germany and Poland, to Crimea and possibly the Caucasus, with parts (at least) of northern Africa and of Asia Minor. Whether he reached farther east, southeast, or south must, notwithstanding some claims, be regarded as still uncertain.

The whole great territory over which his remains have been discovered was doubtless not occupied by Neanderthal man synchronously, or continually, or with equal density. He was evidently not a nomad, though probably more or less of a rover who stayed in a place for a time and then moved away. Some of the deposits he left

show up to six different layers of occupation (Grimaldi, Olha, La Quina, Le Moustier, Krapina, etc.). The density of his remains is greatest in France and Belgium, least in the northeastern limits of his territory and in the mountainous parts, particularly the Alps, Carpathians, and the Balkan Peninsula.

The distribution of Neanderthal man in Europe is of much significance, as will be seen later.

LIMITS AND DURATION

The boundaries and duration of the Neanderthal period are those of the Mousterian culture. They may now be delimited with some

··AREAS OF THE MOUSTERIAN AND AURIGNACIAN CULTURES — EUROPE··

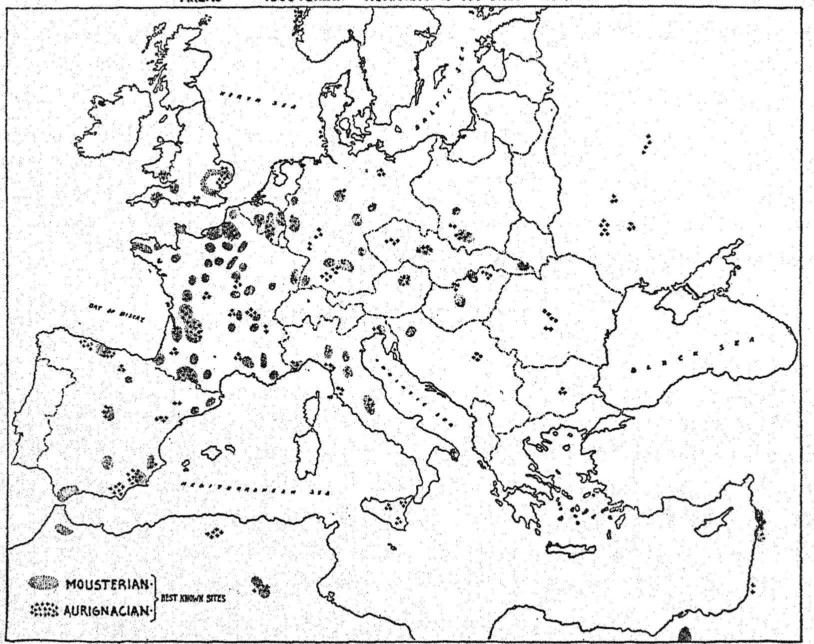


FIGURE 1

precision, though not finality, by data of a paleontological, geological, and archeological nature.

PALEONTOLOGY

Neanderthal man coexisted with a large series of now extinct animals; the question is, how intimately are these forms associated with his coming and going. The Mousterian culture is the culture, essentially, of the earlier times of the mammoth, the woolly rhinoceros, the cave lion, bear, and hyena, the horse, the old ox, the bison, the reindeer, the stag. There are many other forms, but these are the most characteristic.

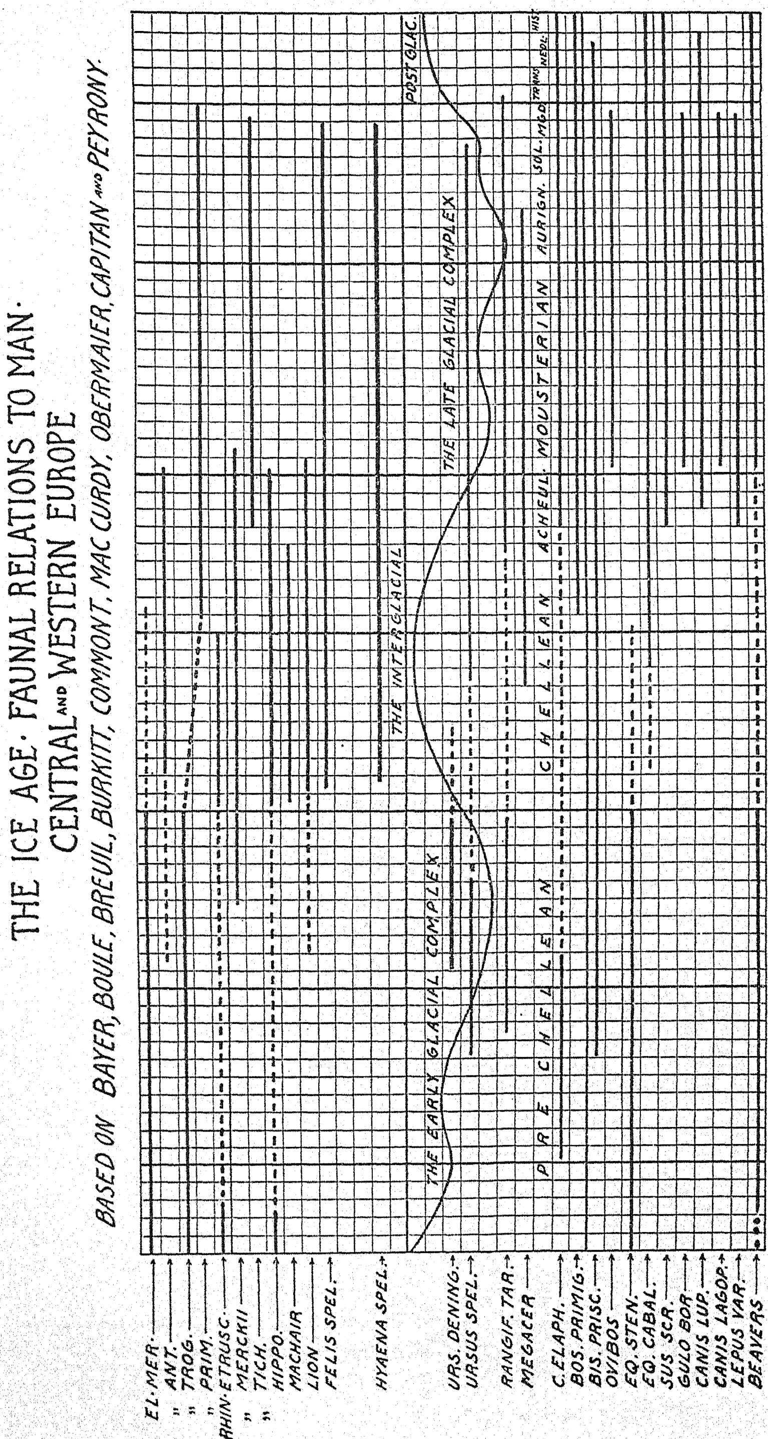

THE ICE AGE · FAUNAL RELATIONS TO MAN ·
CENTRAL AND WESTERN EUROPE
BASED ON BAYER, BOULE, BREUIL, BURKITT, COMMONT, MAC CURDY, OBERMAIER, CAPITAN AND PEYRONY.
EL. MER.
" ANT.
" TROG.
" PRIM.
RHIN. ETRUSC.
" MERCKII
" TICH.
HIPPO.
MACHAIR
LION
FELIS SPEL.
HYAENA SPEL.
URS. DENING.
URSUS SPEL.
RANGIF. TAR.
MEGACER
C. ELAPH.
BOS. PRIMIG.
BIS. PRISC.
OVIBOS
EQ. STEN.
EQ. CABAL.
SUS SCR.
GULO BOR.
CANIS LUP.
CANIS LAGOP.
LEPUS VAR.
BEAVERS
THE EARLY GLACIAL COMPLEX
THE INTERGLACIAL
THE LATE GLACIAL COMPLEX
POST GLAC.
PRE CHELLEAN
CHELLEAN
ACHEUL.
MOUSTERIAN
AURIGN.
SOL.
MGD.
TRANS.
NEOL.
HIS.

FIGURE 2

The Mousterian culture neither comes in, however, nor ends with any of these large mammals. The mammoth, derived probably from the Trogontherium, is present since at least the Acheulean and lasts to, if not beyond, the end of the Magdalenian. The cave lion, bear, and hyena, as well as the horse, ox, bison, and even the reindeer, are all there since or before the beginning of the Acheulean, and they last throughout the Mousterian, Aurignacian, Solutrean, and Magdalenian periods, to disappear gradually during the latter, or persist to historic times.

Mousterian man begins, evidently, during the latter part of the last great interglacial and extends deep into the final glacial time, without perceptible direct relation to the fauna. His remains at Montières, Villefranche, Ehringsdorf, the rock-shelter Olha, some of the Mentone caves, and elsewhere, show still the remains of the *Elephas antiquus*, the Merck's rhinoceros, the large lion, and the panther. On the other hand, various Arctic species (*Ovibos mosch.*, *Gulo bor.*, *Canis lagop.*, *Lepus arct.*, etc.) come in as the cold advances during the Mousterian period, without, however, marking either its beginning or its end.

There is, therefore, no definite line of faunal demarcation for the beginning and none for the end of the Mousterian period. Neanderthal man did not come in with any fauna, nor did he go out with any—which also are facts of importance.

GEOLOGY

Geological information about the Mousterian period is not as precise or full as is desirable, but it permits of several valuable conclusions.

A survey of the better-known Mousterian sites, from Germany and Belgium southward, shows that fully one-third of them were in the open, while of the remainder quite a few (Krapina, Sergeac, La Ferrassie, etc.) are found in and about shallow rock-shelters that could not have afforded much protection. In Switzerland, moreover, the earlier Mousterian man lived in caverns at a high elevation (Wildkirchli, 4,905 feet; Drachenberg, 8,028 feet). All of this indicates that the climate during a considerable part of the Mousterian period was not severe enough generally to drive man into the caves, or even down from the mountains, thus pointing to interglacial rather than glacial conditions.

There is no evidence of any critical geological manifestations, either about the beginning or about the end of the Mousterian period.

The cultural remains of the Mousterian in the open stations, as well as those in caves, denote both considerable age and long duration of the period. In the open the remains lie mostly in old gravels

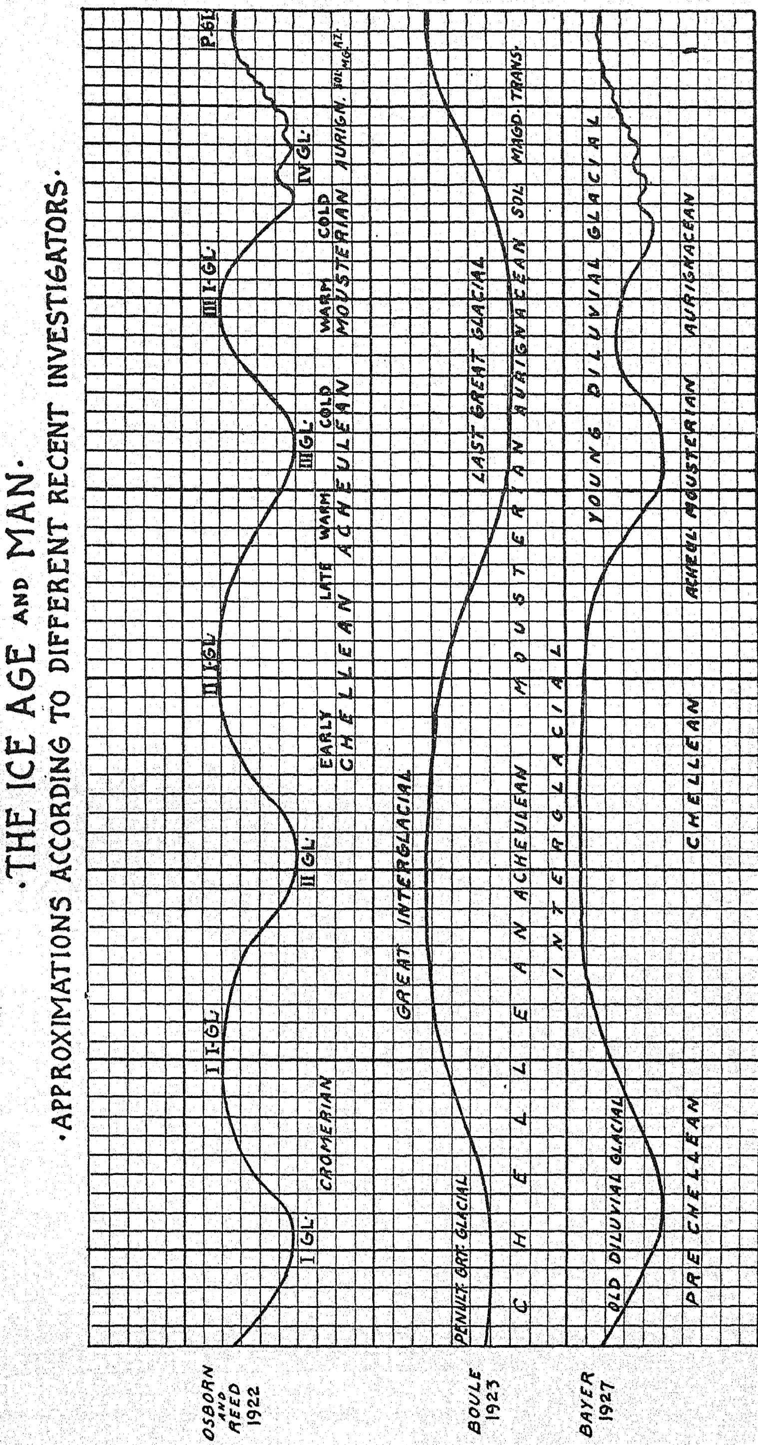

·THE ICE AGE AND MAN·
·APPROXIMATIONS ACCORDING TO DIFFERENT RECENT INVESTIGATORS·
OSBORN AND REED 1922
I GL.
I I-GL.
II GL.
II I-GL.
III GL.
III I-GL.
IV GL.
P-GL.
CROMERIAN
EARLY CHELLEAN
LATE WARM ACHEULEAN
COLD
WARM MOUSTERIAN
COLD AURIGN. SOL. MG. AZ.
BOULE 1923
PENULT. GRT. GLACIAL
GREAT INTERGLACIAL
LAST GREAT GLACIAL
C H E L L E A N ACHEULEAN M O U S T E R I A N AURIGNACEAN SOL MAGD. TRANS.
BAYER 1927
OLD DILUVIAL GLACIAL
I N T E R G L A C I A L
Y O U N G D I L U V I A L G L A C I A L
PRE CHELLEAN
C H E L L E A N
ACHEUL. MOUSTERIAN
AURIGNACEAN

FIGURE 3

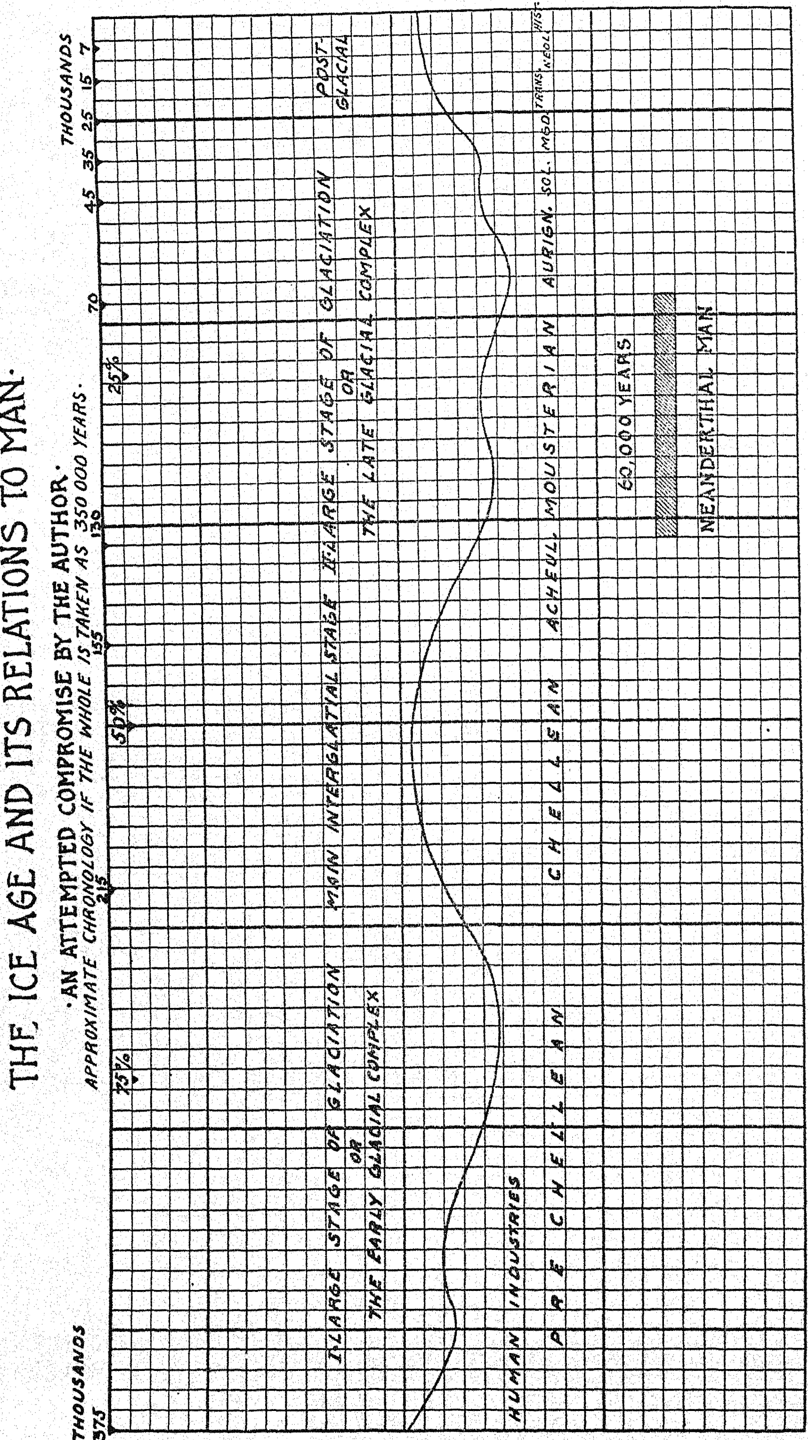

THE ICE AGE AND ITS RELATIONS TO MAN.
·AN ATTEMPTED COMPROMISE BY THE AUTHOR·
APPROXIMATE CHRONOLOGY IF THE WHOLE IS TAKEN AS 350 000 YEARS·
THOUSANDS
375
215
155
130
70
45
35
25
15
7
75%
50%
25%
I. LARGE STAGE OF GLACIATION OR THE EARLY GLACIAL COMPLEX
MAIN INTERGLACIAL STAGE
II. LARGE STAGE OF GLACIATION OR THE LATE GLACIAL COMPLEX
POST-GLACIAL
HUMAN INDUSTRIES
PRE CHELLEAN
CHELLEAN
ACHEUL.
MOUSTERIAN
AURIGN.
SOL.
MGD.
TRANS.
NEOL.
HIST.
60,000 YEARS
NEANDERTHAL MAN

FIGURE 4

or sand, rarely in clay or loess, or in travertine rock of lacustrine origin. There may be two or three cultural strata or horizons (as at Ste. Walburge, High Lodge, Ipswich, Amiens, etc.), indicating a repeated occupation of the same site after shorter or longer intervals, though there have not been found as many occupational layers as in some of the caves.

ARCHEOLOGY

Neither paleontology nor geology explains Neanderthal man; perhaps we may learn more from archeology.

The main archeological questions are: How does Mousterian man differ in habits and arts from the man that preceded him, and from him that followed? And are the differences, or are they not, substantial enough to brand him as something apart from either his predecessors or his followers?

OCCUPATIONS

The chief activities of man in nature relate to his housing, to the obtaining and preparing of food, and to the manufacture of tools, utensils, and weapons. Let us see briefly how Neanderthal man compared in these respects with his forbears and his followers.

Housing.—There is a prevalent idea that Neanderthal man was essentially a cave dweller, and this idea seems generally to carry with it a sense of inferiority. The records now available throw a different light on this matter. Analysis of 360 better-known paleolithic sites in Europe and the neighboring regions (from records compiled principally by MacCurdy) gives the following interesting information:

Dwellings in the open and in caves during paleolithic times

Period	Sites in the open		Rock shelter or cave	
	Number	*Per cent*	*Number*	*Per cent*
Pre-Chellean	11	100		
Chellean	32	94	2	6
Acheulean	36	78	10	22
Mousterian	45	34	88	66
Aurignacian	24	18	112	82
Solutrean	10	14	62	86
Magdalenian	17	10	148	90
Azilian and Tardenoisian	4	9.5	38	90.5
Accompanying Neolithic	22	22.5	76	77.5

The figures and chart (fig. 5) show some curious and important facts. Man begins as a dweller in the open, but since the warm Chellean already he commences also to utilize the rock shelters and caverns, and then as the climate cools he gradually takes more and more to the caves. In these phenomena the Mousterian period shows nothing striking, nothing individual. It falls harmoniously into the curve of the progress of cave dwelling, to be followed equally harmoniously by the Aurignacian and the succeeding periods. Mous-

terian man occasions no disturbance in the human housing conditions of the time, and, what is even more remarkable, no disturbance or change whatsoever is occasioned by the advent of the Aurignacians. Aurignacian man follows in the footsteps of his predecessor without interruption. Like the Neanderthaler, he builds in the open huts of perishable materials that leave no trace, and he utilizes the caves exactly as much as, and eventually even more than, the Neanderthal man. He continues, in fact, on many of the same sites and in most of the same caves that the latter has used, without introducing any innovation. He, also, like the Neanderthal man, leaves here and there a whole series of occupational strata which testify to much the same habits of life. Yet Aurignacian man is represented as a newcomer of a different species from that of the Neanderthaler and mentally vastly superior.

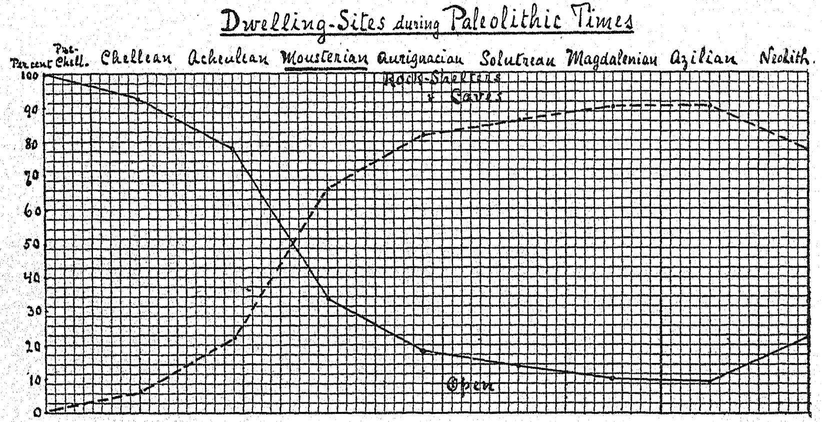


FIGURE 5

Food.—Neanderthal man was chiefly a hunter of the larger mammals of his time. He knew fire, but knew not domestication of animals or agriculture. He compared in these respects with the preceding and following man as follows:

Food and habits relating thereto

Acheulean man	Mousterian man	Aurignacian man
Chiefly a hunter. Fisher (?). Use of mollusks—no trace. Knew fire. Preparation of food: probably by roasting on fire or coals—no trace of any vessels for boiling. No agriculture. No domestication of animals. Bones broken for brains and marrow. Bones and refuse accumulations in inhabited caves, and in front of them. No trace of storage of food. Pictorial representation of hunted animals—not known.	Chiefly a hunter. Fisher (?). Use of mollusks—no trace (?). Knew fire. Preparation of food: probably by roasting on fire or coals—no trace of any vessels for boiling. No agriculture. No domestication of animals. Bones broken for brains and marrow. Bones and refuse accumulations in inhabited caves and in front of them. No trace of storage of food. Pictorial representation of hunted animals—none known yet.	Chiefly a hunter. Fisher (probably). Use of mollusks (?). Knew fire. Preparation of food: probably by roasting on fire or coals—no trace of any vessels for boiling. No agriculture. No domestication of animals. Bones broken for brains and marrow. Bones and refuse accumulations in inhabited caves and in front of them. No trace of storage of food. Pictorial representation of hunted animals—gradual development.

Evidently, in food and food habits, as in housing, Mousterian man was quite like both the Acheulean man that preceded him, and the *Homo sapiens* that followed.

Clothing.—About the clothing of Neanderthal man we know nothing direct, as is also the case with Acheulean and Aurignacian man. But the cool climate, on the one hand, and the much increased numbers of tools with a cutting edge, and especially scrapers, on the other hand, indicate extensive preparation of the skins of animals, to be used, doubtless, for clothing and bedding. No sudden change in these connections is observable from the Acheulean to the Aurignacian.

Tools.—The Mousterian period is characterized by a definite phase of stone industry, but so are all the periods before and after it. It has no abrupt beginning. It uses flint where this can be had, as do all the other industries; where flint is absent or scarce, it employs quartzite and other stones. The use of bone begins in the Mousterian, to increase henceforward. The period shows three stages of evolution, the lower, middle, and upper, as do also later the Aurignacian and the Magdalenian periods. The implements range from crude to beautifully made (as at La Ferrassie, La Quina, Le Moustier); the technique is partly different from, but in general not inferior to, either the late Acheulean or the earlier Aurignacian; and there are indications that there was no general sudden ending.

On the whole the Mousterian industry, though characteristic, does not provide evidence of something entirely new and strange, intercalated between the Acheulean and the Aurignacian, beginning abruptly by displacing the former or ending suddenly through displacement by the latter. There is much in fact at either end that may prove to be, more or less, of a transitional nature.

Thus, in H. F. Osborn's opinion (Obermaier, 1924, p. x), the Mousterian "constitutes a further evolution of the two earlier cultures"—the Chellean and the Acheulean. At Ehringsdorf, in the lower travertine, "the technique of the chipping is Acheulean, but the forms are largely Mousterian" (MacCurdy, Human Origins, 1924, Vol. II, p. 392). According to Burkitt (Prehistory, 1921, p. 27), ". . . workers in Dordogne find a great difficulty in distinguishing between Upper Acheulean beds and Lower Mousterian beds. In fact, M. Peyrony often only solves the problem by the absence or presence of reindeer." And quotations of similar import could be multiplied. As to the upper limits—at the Cotte de Ste. Brelade, Jersey, excavated by Nicolle, Sinel, and Marett, the upper (fifth) layer gave graceful implements "that may be either Upper Mousterian or Aurignacian" (Burkitt). At Le Moustier, the type station of the Mousterian industry, the upper rock shelter showed eight layers, "the top one being Aurignacian, the second transitional (Audi), and the rest Mousterian, except the seventh which was sterile." The lower

rock shelter was even more instructive. The section from top to base was: (6) Lower Aurignacian; (5) Transitional (Audi); (4) Typical Mousterian; (3) Mousterian with Audi forms and few *coups-de-poing;* (2) Mousterian with some Audi forms and many *coups-de-poing;* (1) some Audi forms, no *coups-de-poing* (Burkitt, 1921, p. 93). But perhaps the best comprehensive statement on this subject is that of MacCurdy, one of the oldest and most cautious students of prehistory. In his Human Origins, 1924, Vol. I, pp. 161–62, we read:

In certain French stations, a transition from the Mousterian to the Lower Aurignacian occurs, as for example, at Le Moustier (Dordogne), La Verrière (Gironde), and especially at the rock shelter of Audi in the village of Les Eyzies. In comparison with Mousterian points, those of Audi are more slender and are slightly recurved. The convex margin is rendered blunt by retouching so as not to injure the hand while using the opposite margin for cutting or other purposes. Such a tool, as much a knife, or scraper, as a point, bridges the gap between the Mousterian point or double scraper and the Lower Aurignacian blades of the Châtelperron type. At Audi it is associated with small cleavers and disks, scrapers, spoke shaves, asymmetric points, and scratchers. The Grotte des Fées at Châtelperron, though distinctly Aurignacian, is so closely related to the transition stage that the chronologic difference must be small. An intermediate stage is recognizable at La Ferrassie (Dordogne).

The Audi culture is still somewhat controversial, Abbé Breuil (recent letter) regarding it as "degenerate Mousterian." Notwithstanding this, the impression is growing that the more the initial and the terminal stages of the Mousterian industry are becoming known, together with the late Acheulean and the earliest Aurignacian, the less abrupt and striking appear their differences and the greater grows the feeling that they are not absolutely separated. Some interesting things in this connection have been seen at Spy, and others are now appearing to Absolon in Moravia.

SEQUENCE OF CULTURES

The sponsors of the view that Aurignacian man was a man of different and superior species to the man of the Mousterian period, conceive him for the most part, apparently, as an invader who came from somewhere outside the Neanderthal area, overwhelmed completely the established less capable species, and annihilated or at least wholly replaced it, over all the great domain over which it once extended. These ideas, however, are never expressed very clearly, and little thought is given to the incongruities they involve.

They would imply, first of all, the invasion of Europe during the height of the last glaciation. This is not in harmony with the main laws of human and biological spread—namely, movement in the direction of least resistance, and movement in the direction of better material prospects, which are, first of all, climate and food. In the

entire history of Europe the movements of men have tended always toward "a place in the sun" and away from the cold.

Such views postulate, next, large numbers of the newcomers to suffice for the vast task. But such large numbers would necessarily mean somewhere near a still larger mother population, and there is no trace, either in western Asia or northern Africa, the only regions from which such invasions at those times would have been practicable, of any such numerous Aurignacian population.

It is a very serious question whether in paleolithic times, when man was without a tamed animal, without stocks of nonperishable food, dependent wholly on hunting without yet a bow and arrow, and in the imperfect social organization of that time, any large armed invasion would have been feasible. A peaceful extension, on the other hand, would not lead to the annihilation or expulsion of the invaded population, and if small or gradual, would lead to an amalgamation with, rather than the extinction of, the native stock. A complete displacement by any agency is difficult to conceive, and there would remain to be explained the fate of the displaced people.

It stands to reason that these great difficulties would have to be satisfactorily explained away before there could be a general intelligent acceptance of an Aurignacian invasion with Mousterian extinction.

Finally, the coming of a distinct and superior species of people ought to have left a very tangible record on the sequence and nature of the cultural levels of the two stocks.

As to sequence, 257 of the better-known and recorded Mousterian sites (as recorded by MacCurdy) give, on analysis, the following conditions:

Sequence of industries

	Open stations		Rock-shelters and caves	
	Number	*Per cent*	*Number*	*Per cent*
Mousterian topped by—				
(No culture)	(34)	(55.7)	(15)	(18.9)
Neolithic	4	6.6	4	5.1
Magdalenian	3	4.9	9	11.4
Solutrean	2	3.3	10	12.7
"Paleolithic"	1	1.6	2	2.5
Aurignacian	17	27.9	39	49.4
Mousterian, number of stations	(61)		(79)	
	(54)		(63)	
Mousterian reposing on—				
Acheulean	24	44.4	4	6.3
Chellean	5	9.3	3	4.8
(No culture)	(25)	(46.3)	(56)	(88.9)

The Mousterian culture, in nearly one-half of its stations in the open, follows direct upon the Acheulean; and the Aurignacian, in very nearly one-half of the rock shelters and caves, and in not far from one-third of the stations in the open, follows upon the Mouste-

rian. It would seem that these figures speak for a rather close relation of these peoples in their habits, and that particularly between the Mousterians and Aurignacians—who should represent two different species of man, one greatly superior to the other.

An objection may here be raised to the effect that the number of available, and especially of the more suitable, caves was limited and, therefore, the same caves that once served the Neanderthalers had to be used also by the shelter-needing Aurignacians; but this point is invalidated by the showing of the Solutreans and Magdalenians, who were even more cave dwellers than the Aurignacians, yet are found collectively in less than one-fourth of the Mousterian caves.

Another point is, that it is not always the lower or earliest Aurignacian that follows upon the Mousterian. But such a discord is common to all the periods. It may mean a discontinuity, and may also mean a persistence of any given culture in some localities longer than in others. In both cases it would speak against a sudden general displacement of one culture.

There is evidently much here, once more, to be explained by those who conceive of Aurignacian man as very distinct from, and superior to, the Mousterian, and as having suddenly replaced the latter.

ART

The Aurignacian period does not appear to come in full-fledged, as is sometimes taken for granted, but to develop locally, both in industry and art, from humbler beginnings (Breuil, Burkitt, Evans, MacCurdy, et al.). Also there seems to be more difference in these respects between the lower and the middle Aurignacian than there is between the lower Aurignacian and the upper Mousterian with the Audi and the Châtelperron stages.

It may, moreover, be unjust to assume that Mousterian man was devoid of art sense. He may not have left any designs in caves (though that is not perhaps absolutely certain), but the same is true of the Neolithic and many other early, as well as later, populations. How many such designs, or other permanent forms of art, for instance, have been left by the prehistoric man of England, or Belgium, or Germany, Moravia, Poland, or Russia? How many have been left more recently by such highly artistic people as the Slovaks and the peoples of the Carpathians and the Balkans? And how many cave designs comparable to those of France and Spain do we find in the whole continent of America, with all its able and highly artistic population, a large part of which—the Lagoa Santa-Algonkin type—may even be remotely related to the Aurignacians? On the other hand, practically a replica of the European cave art was produced by the lowly Bushmen of South Africa, who certainly were no superior race or species.

That the Mousterians may not have been lacking in artistic sense is indicated by some of their beautiful implements from La Quina and other stations; by the beautiful topaz and crystal cleavers found since 1925 by the American school at Sergeac; by the decorated bone fragment from La Ferrassie; and possibly by the *pierres-figures* (e. g. Roellecourt, Dharvent), and used chunks of manganese oxide, found occasionally in the Mousterian deposits (La Quina and elsewhere). Sir Arthur Evans tells us that "When we turn to the most striking features of this whole cultural phase, the primeval arts of sculpture, engraving, and painting, we see a gradual upgrowth and unbroken tradition. From mere outline figures and simple two-legged profiles of animals we are led on step by step to the full freedom of the Magdalenian artists." (New Archæological Lights on the Origins of Civilization in Europe, by Sir Arthur Evans, Science, 1916, n. s. xliv, No. 1134, p. 406.) MacCurdy is even more direct: "The inception, development, and decay of Quaternary art all took place during the upper paleolithic period. The beginnings of sculpture, engraving, and fresco are traceable to the Aurignacian epoch" (MacCurdy, Human Origins, Vol. I, p. 155). And there are some very good words of appreciation of the abilities of Mousterian man in Sir Arthur Keith's recent two volumes (The Antiquity of Man, 1925, I, 223). Thus—archeology fails also, as did paleontology and geology, in isolating Neanderthal man, and in separating him from the succeeding forms of humanity.

III. THE SKELETAL REMAINS

THE SKELETAL MATERIAL

The crucial part of the whole question of Neanderthal man is, however, that of the evidence of the skeletal material, for it is essentially upon this that the separateness and discontinuance of the Neanderthal type of man has been based. It would probably be easy to harmonize all the rest of the differences between Neanderthal and later man with the idea of a simple evolution and transmission, were it not for the obstacle of the Neanderthal man's skulls and bones. These impress one by such marked differences from those of any later man, that a bridging over of the gap has, to many, seemed impossible.

Let us glance at what the present skeletal evidence of Neanderthal man consists of. Leaving out of consideration the unimportant and the doubtful specimens, the remains comprise now the following (pp. 609 to 611).

It will be well in this connection to contrast the Neanderthal remains with those from the Acheulean on one side, and those from

the Aurignacian and the following periods on the other. The results are unexpected. There is nothing authentic from Acheulean times; and there is less, in the number of finds, from the Aurignacian than there is from the Mousterian period. Moreover, what there is from the Aurignacian is found, on consulting the details of the discoveries, to be essentially middle and upper, rather than the most-needed early Aurignacian. The data leave a strong impression that the material, but especially that from the earlier portion of the Aurignacian period, is still far from sufficient for drawing from it far-reaching inductions.

Neanderthal remains in chronological order of discovery

Name of find	Year of discovery	By whom discovered	Find consists of—	Essential data or discovery	Reported by and when (originally)
Gibraltar	1848	Laborers	Adult female skull, damaged (without lower jaw).	Found accidentally, in a crevice during blasting for an emplacement of a battery.	G. Busk, 1868.
Neanderthal	1856	Laborers	Adult male skull-cap, and 13 bones of the skeleton.	Found accidentally in a cave	C. Fuhlrott, 1857; D. Schaaf-hausen, 1858.
La Naulette	1866	E. Dupont	Imperfect lower jaw of a young adult woman.	Excavated from undisturbed deposits in Troue de la Naulette, near Dinant, Belgium, under layers of stalagmite alternating with six layers of earth, the two 12 feet in thickness.	E. Dupont, 1866.
Sipka	1880	Karel J. Maška	Fragment of the frontal part of the lower jaw of a child of about 8 years.	Excavated from the "Badger hole," a low lateral extension of the Sipka cave. Lay 1.4 meters deep in undisturbed ash bed. Freed from a lump of ashes, suffering thereby probably the loss of a tooth and some small pieces of bone (Maška).	Wankel, 1880; Schaafhausen, 1881 and 1883; R. Virchow, 1882; Maška, 1886.
Spy No. 1 and No. 2	1886	Marcel de Puydt and Maxim Lohest.	Two skeletons, males, adult.	Excavated from terrace in front of a cave, 6 and 8 meters distant from entrance, 4 meters deep.	J. Fraipont and M. Lohest, 1887.
Bañolas (Gerona, Spain)	1887	Lorenzo Roura	Lower jaw	In hard travertine, about 15 feet from surface	Cazurro, 1909; Harlé, Pacheco and Obermaier, 1912.
Malarnaud (Ariege)	1889	F. Regnault	Lower jaw, adult female	In ancient clay, with bones of extinct animals, capped by a layer of stalagmite.	H. Filhol, 1889.
Krapina (Croatia)	1895, 1899, and 1905	K. Gorjanović-Kramberger	Parts of over 20 skeletons (adult and subadult, both sexes.)	Excavated from the fillings of an old rock shelter, with remains of fire, bones of extinct animals, and stone implements.	Gorjanović-Kramberger (various dates).
Le Moustier (Dordogne)	1908	O. Hauser	Skeleton of an adolescent male.	Excavated from an accumulation of cultural débris of Mousterian age, in lower rock shelter, at Le Moustier.	O. Hauser and H. Klaatsch, 1909.
La Chapelle (Correze)	1908	Abbés A. Bouyssonie, J. Bouyssonie, and L. Bardon.	Skeleton (male, middle-aged).	Burial (formal) in a depression dug in the marly soil of the floor of a cave.	A. and J. Bouyssonie and L. Bardon, 1908; M. Boule.
Jersey (Channel)	1910	MM. Nicolle and Sinel	13 teeth (from both jaws) of one skeleton.	Cave accumulations, near an ancient hearth	R. Marett, 1911; A. Keith, 1911.
La Quina (Charente)	1908–21	Henri Martin	Skeleton of an adult (1911); lower jaw (1912); skull of a child (1921); fragments of several skeletons (different dates).	Partly in ancient mud-bed of the near-by stream (adult skeleton, etc.); partly in kitchen refuse and débris (child skull, etc.).	H. Martin, 1911–27.
La Ferrassie (Dordogne)	1909, 1910, and 1912	Peyrony	2 skeletons (adults—a male, a female)—and traces of 4 children.	At base of accumulations in a shallow rock shelter.	Capitan and Peyrony, 1909, 1912.

Neanderthal remains in chronological order of discovery—Continued

Name of find	Year of discovery	By whom discovered	Find consists of—	Essential data or discovery	Reported by and when (originally)
Ehringsdorf (Weimar)	1914, 1916 (and later).	Quarrymen	2 lower jaws, remains of a child's skeleton, portion of a thigh-bone.	Deep in hard travertine (and intercalated layer)	G. Schwalbe, 1914; H. Virchow, 1920.
Galilee	1925	F. Turville-Petre	Fragments of the skull of a young adult, including the frontal-bone.	Cave, at the base of undisturbed paleolithic layer, 6½ feet below the modern floor-level.	F. Turville-Petre and Arthur Keith, 1927.
Ehringsdorf (Fischer's Quarry).	1925	Quarrymen	Broken vault of an adult skull.	Deep in hard travertine	F. Weidenreich, 1927.
Gibraltar	1926	Miss D. A. E. Garrod	Skull of a child of about 10 years of age.	Rock shelter, with Mousterian culture	Abbé Breuil (shelter); Miss D. A. E. Garrod (prelim. notes), 1926.

The more important and better authenticated remains of early man from the Acheulean period onward

Acheulean	Mousterian	Aurignacian	Solutrean	Magdalenian
(?) Taubach (teeth).	(1) Gibraltar (skull).	(1) Most (Brüx) (skull).	(1) Laugerie-Haute (skeleton).	(1) La Madeleine (skeleton, fragments of jaws).
(?) Ehringsdorf (2 lower jaws).	(2) Neanderthal (skeleton).	(2) Combe-Capelle (skeleton).	(2) Badagoule (Dordogne) (1 child's skeleton).	(2) Laugerie-Basse (skeleton).
	(3) La Naulette (lower jaw).	(3) La Rochette (parts of skeleton).	(3) Klause, near Neu-Essing (skeleton).	(3) Chancelade (skeleton).
	(4) Šipka (lower jaw).	(4) Camargo (skull).		(4) Cap Blanc (skeleton).
	(5) Spy (2 skeletons).	(5) Castillo (lower jaw).		(5) Duruthy (near Sord Es Landes) (skeleton).
	(6) Bañolas (lower jaw).	(6) Hôhlefels (lower jaw and teeth).		(6) Les Hoteaux (near Rossillon, Ain) (skeleton).
	(7) Malarnaud (lower jaw).	(7) Enzheim (skeleton).		(7) Lussac-le-chateau (lower jaw).
	(8) Krapina (parts of over 20 skeletons).	(8) Mentone (8 skeletons).		(8) Grotte-des-Fees (parts of jaws).
	(9) Le Moustier (skeleton).	(9) Paviland (skeleton).		(9) Le Placard (skull and fragments).
	(10) La Chapelle (skeleton).	(10) Ojeów (portion of a skull).		(10) Mas d'Azil (skull).
	(11) Island of Jersey (teeth).			(11) Obercassel (2 skeletons).
	(12) La Quina (skeleton; skull of child, lower jaw, parts of several skeletons).	*Aurignacian, probably*		(12) Freudental (lower jaw an numerous fragments).
	(13) La Ferrassie (2 adult skeletons, traces of 4 children's skeletons).	Brno (Brünn) (1 skull, 2 skeletons)		(13) Miskolez (child's skull).
	(14) Ehringsdorf (?) (2 lower jaws, child's skeleton, part of a femur).	Předmost (remains of about 20 individuals, 14 skeletons fairly complete)		
	(15) Near Ehringsdorf (skull).	Solutré (3 skeletons)		
	(16) Galilee (skull).	*Aurignacian or later*		
	(17) Gibraltar (child's skull).	Cro-Magnon (2 skeletons, parts of 3 others) Halling (1 skeleton)		

Taking the Neanderthal remains by themselves, we find that, notwithstanding their defects, they constitute a very respectable array of precious material. Let us see what it teaches.

If we placed all this material on a table before us, ranged by the date of discovery, we should see a remarkable assembly of more or less deficient or fragmentary skulls, jaws, and bones, with an array of loose teeth, the whole differing widely in color, weight, state of petrifaction, and in principal morphological characters. We should be struck by the prevailing aspect of inferiority of the material, but the arrangement would soon prove unsatisfactory and we should proceed to another.

As there is not enough for a geographical subdivision, it would be logical to try next an arrangement of the specimens by their antiquity, from the oldest to the latest. The indications are that the Mousterian period was a long one, and of three stages—the inferior, middle, and superior. We should like, therefore, at least to arrange our material by these stages.

But we strike at once great difficulties. The very type-specimen of the lot, the Neanderthal skeleton, lacks direct chronological identification. There were neither animal nor industrial remains with it, or, if there were, they were not saved. Everything indicates that it is very old: Physically it is in every one of its parts a prototype of Mousterian man; chronologically it may be even pre-Mousterian. Similar and other difficulties confront us in the case of the first Gibraltar skull and the Bañolas jaw, the important Krapina remains, the Ehringsdorf jaws; and it is not certain just where within the period to place most of the remainder of the specimens. The final conclusion is that, if the eyes are shut to the somatological characters of the remains, a satisfactory chronological grading of them becomes very difficult and uncertain.

The state of preservation or petrifaction of the remains is a question of local geophysics and chemistry, and thus incapable of giving any fair basis for classification. Thus there remain only the somatological characteristics of the skulls and bones themselves, and the endeavor to arrange them on this basis proves of much interest.

The general physical characters of the Neanderthal race have been more or less summed up by a number of eminent anatomists and anthropologists, including especially Schwalbe, Keith, Sollas, and Boule. The main features of the average Neanderthaler are therefore fairly well known. They include a moderate stature, heavy build, and a good-sized, thick, oblong skull, with pronounced supra-orbital torus, low forehead, low vault, protruding occiput, large, full upper maxilla, large nose, large teeth, and a large, heavy lower jaw with receding chin. To which may be added stout bones of the skeleton, particularly the ribs and the bones of the lower part of the

body, arched radii and femora, femora and tibiæ with heavy articular extremities, the tibia relatively short and with head more than now inclined backward, a peculiar short astragalus, and various other primitive features.

To this generalized type some of the specimens conform, it is soon seen, much more than others. It is realized that the general conception of the type has been built up essentially on the Neanderthal, Spy No. 1, the La Chapelle, and the La Quina skulls and skeletons, but that from this generalization there are many aberrations.

An arrangement of the specimens in morphological order, beginning with those that show the most primitive or old features and advancing gradually toward more modern standards, is now in order, and the results are very striking.

The first strong impression is that, with all the seeming riches, there is still not enough material for satisfactory grading. The next appreciation is that it is hard to grade whole lots, but that it is necessary to grade the skulls, jaws, teeth, and bones separately. In one and the same skeleton are found parts and features that are very primitive and far away from man's later types, with parts and features that are almost like the modern; and every skeleton is found to differ in these respects. Here is facing us, evidently, a very noteworthy example of morphological instability, an instability, plainly, of evolutionary nature, leading from old forms to more modern.

The Neanderthal skull and skeleton proper, in all the parts that have been saved, is found to stand at the base of the series. It lacks, regrettably, the lower jaw and the teeth, as well as the sternum, most of the scapulæ, and the ribs, vertebræ, sacrum, the leg, the hand, and the foot bones. Of what is present, the farthest from modern type is the skull, the next being the thigh and the leg bones; the nearest to modern forms, though still somewhat distinct, are the bones of the upper extremity.

The closest in general to the Neanderthal skeleton is Spy No. 1, La Chapelle, and apparently the Le Moustier youth. But Spy No. 1 has almost primitive-modern jaws with practically recent teeth; the La Chapelle shows high cranial capacity, an "ultra-human" nose, and a strongly developed nasal spine; the Le Moustier skull has a higher vault and forehead, with less protrusion of the occiput; while the bones of the upper extremity in all three approach closely the modern types. Thus, even in these most nearly related four specimens, there is in evidence a considerable variability, with more or less advance in various parts in the direction of later man.

These facts deserve, undoubtedly, earnest consideration. But there is much more to be learned. Taking the remainder of the skulls, jaws, and bones attributed to the Neanderthal phase, it is seen that

both the variability and the number of characters that tend in the direction of later man increase considerably. The Krapina series, by itself, is probably more variable from the evolutionary point of view than would be any similar series from one locality at the present. This is true in respect to the cranial form, the development of the forehead, the jaws, the teeth, and many of the bones of the skeleton. The additional Neanderthal remains manifest signs of similar instability of type and of tendencies of an evolutionary nature, this being particularly true of Spy No. 2, and of the recently discovered Galilee and Ehringsdorf crania.

In his excellent description of the Galilee specimen, Sir Arthur Keith has shown that it has a fair forehead, with "no suggestion in the vaulting of its frontal bone that the roof of the skull was low and flat, as is usual in Neanderthal skulls." And in his preliminary report on the Ehringsdorf (1925) cranium, F. Weidenreich shows us a specimen with even better developed frontal region, and a vault of good height.

But the most instructive, though most neglected, specimens are the crania of Spy, Belgium. Here the student is confronted with a find in the same terrace and deposits, at the same level, and but 6 feet apart, of two adult male skeletons from the later Mousterian time. One of these skeletons, No. 1, has a skull the vault of which is a replica of that of the Neanderthal cranium, with typically Neanderthal bones of the skeleton. But this same skull is associated with upper and lower jaw and teeth that may be duplicated to-day among the lower races. And the skull of the second skeleton is so superior in size, shape, height of the vault, and height of the forehead, to No. 1, that the morphological distance between the two is greater than that between No. 2 and some of the Aurignacian crania, such as the Most (Brüx) or Brno No. 1 (Brünn) specimens.

About the most distinguishing and important marks of difference of the typical Neanderthaler from later man, are, we may repeat, the flatness of his head, with low receding forehead and a peculiar protruding occiput; heavy, supraorbital torus; heavy, chinless jaw; and, as determined from intracranial casts, a low type of brain. It will be well to see how these characters stand the light of our present knowledge.

Lowness of the vault, low and receding forehead, and projecting occiput, all show in the series of the Neanderthal skulls known to-day a large range of gradation, the lower limits of which are well below, but the upper grades of which are well within, the range of variation of the same characters in later, and even present, man. There exists to-day a whole great stream of humanity, extending from Mongolia deep into America, which is characterized by low vault of the skull. (See Catal. Crania, U. S. Nat. Mus., Nos. 1 and 2; also Bull.

33, Bur. Amer. Ethn.) Low foreheads are frequent in prehistoric America (see Bull. 33, Bur. Amer. Ethn., and Proc. U. S. Nat. Mus., 1908, vol. xxxv, pp. 171–5). The pronounced Neanderthal occiput, such as shown by the La Chapelle, La Quina, and La Ferrassie skulls, it would be difficult to fully match in later man, but on the one hand the character is not equally marked in all the Neanderthalers, while on the other hand there are decided approximations to it among recent skulls.

A heavy supraorbital torus, such as is common to the Neanderthal skulls, is not found in later man; but not all the Neanderthalers had the torus equally developed (e. g. Gibraltar), and, as has been pointed out by Huxley, Sergi, Stolyhwo, and others, there are later male skulls in which there is a marked approach to the torus. A whole series of specimens may be mentioned (Podkoumok, Brüx, Brno No. 1, Předmost, Obercassel, Alcolea, Djebel-Fartas, two neolithic skulls at Warsaw, the neolithic miner from Strépy at Brussels, etc.) in which the feature is of a distinctly transitional character. Moreover, it is well known that, first, the torus is essentially a sexual (male) and adult feature; second, that a reduction of such characters is easier than that of those which are more deeply rooted; and third, that in the civilized man of to-day a continuance of such reduction is still perceptible. There is less difference in this respect between the Neanderthal and the skulls just mentioned than there is between these and the mean development of the ridges in the highly cultured man—or, for that matter, the ordinary African negro—of the present.

Heavy, large, and receding lower jaws, such as the La Chapelle, La Quina H–5, and some of the Krapina specimens, are among the most striking characters of Neanderthal man. Jaws such as these are not known in later skulls. But with them we have within the Neanderthal group itself specimens very much more advanced morphologically toward the present human type, such as Spy No. 1, La Quina (1912), and the La Ferrassie. Even at Krapina itself some of the jaws are of a less primitive type than others. Let us add to this the various huge, nearly chinless, and even receding jaws that occur now and then in the Australian, Melanesian, Mongolian, American Eskimo, and Indian, and the picture loses much of its discontinuity. Much the same may be said also of the teeth. Teeth of primitive form—incisors, canines (*dents de chien*), molars—occur to this day (see *Amer. Journ. Phys. Anthrop.*, 1922–1924), while practically modern teeth may already be observed in Spy No. 1, and more or less also in other jaws of the Neanderthal group.

As to the bones of the skeleton, the conditions are quite as significant as those of the jaws and teeth. There are scales of gradation from forms that stand considerably apart from those of later man

(as in Neanderthal, Spy, La Chapelle, Le Moustier) to forms that approach to, or merge with, the modern (parts of the Krapina, La Ferrassie, La Quina skeletons). To which may be added a word about the brain.

The size and its variation in the Neanderthal brain are comparable with those of the Aurignacian, and even the present primitive man. The idea that the Aurignacians were exceptional in this respect is, if due regard be given to the factor of stature, erroneous. The surface conformation of the brain, as shown by intracranial casts, is of a low type in the Gibralter, Spy I, La Chapelle, and other specimens. But this does not hold true of the Weimar or the Galilee brain. The intracranial cast of the Galilee skull shows, in the words of Sir Arthur Keith, that "in its mass and its markings it has reached at least to the level attained by individuals in living races—such as that represented to-day by the aborigines of Australia." (Report on the Galilee Skull, p. 106.)

IV. RECAPITULATION

In relation to what perhaps was its most important period, the Mousterian, prehistory is found to have reached a position approaching dogmatism. But this has only led it into a blind alley from which so far there has been found no exit, notwithstanding much speculation.

It has been decided, on the weight of a limited initial group of specimens, that Neanderthal man was a man of a different species; that he may possibly have originated from his European predecessors, but that, after a long period of existence and after having spread far and wide, he perished rather abruptly and completely, without leaving any progeny, on the approach of a superior species, the *Homo sapiens*.

This *H. sapiens* has been assumed to have come from elsewhere, possibly from Africa or Asia; or he was, somehow, cryptically, coeval from far back with the pre-Neanderthaler and the Neanderthaler, eventually to assert himself suddenly and completely, to take over the human burden. He comes on the stage in body and brain largely as he is to-day, and has, since the beginning of the Aurignacian, undergone but moderate alteration.

A whole line of the foremost workers in prehistory are seen to have become identified with these notions, which obliges every student to give them an earnest and respectful attention. But no notion or dogma can possibly reach the status of a fact before it has been proven to be such through full demonstration.

Owing to scarcity of material, such demonstration has hitherto been impossible; but the more the material remains of early man

accumulate and are better understood, the more it is sensed that the whole Neanderthal question is in need of a revision.

If the given assumptions are true, then we are confronted by some strange major phenomena, viz, a long double line of human evolution, either in near-by or the same territories; a sudden extinction of one of the lines; and evolutionary sluggishness or pause in the other. The consideration of these hypotheses brings us into a maze of difficulties and contradictions.

They lead to an outright polygeny—which is undemonstrable and improbable; or they concede the evolution of *H. sapiens* from the same old stock that gave also *H. neanderthalensis*, but deny the possibility of such evolution from Neanderthal man later on; they give us *H. sapiens*, without showing why, or how, and where he developed his superior make-up, and imply that, while he evidently developed much more rapidly at first to reach the status of *H. sapiens*, he then slackened greatly to remain, from the beginning of the postglacial to this day, at nearly the same evolutional level.

They place *H. sapiens* in Africa or Asia, without troubling to offer the evidence of his ancient dominion in those regions. Or, if he lived in Europe, coexisting with the Neanderthaler, where are his remains, and why did he not prevail sooner over his inferior cousin? His traces, it will be recalled, never, in Europe or elsewhere, precede or coexist with, but always follow, the Mousterian. And where are there any other examples of a sudden, complete extinction of a whole large group of humanity; or of any wholesale Aurignacian conquest; or of any superior mentality of the *early* Aurignacians? And where are, in fact, in anything like a sufficient number, the undoubted skeletal remains of the early Aurignacians that could be used for comparison? Why did they, a new, superior species, strong and able enough to completely do away with the Neanderthaler, take over the poor Neanderthaler's caves and sites and live in them exactly, except for some technical differences in stone chipping, as did their crude predecessors? And how shall we explain the anomalous fact of an invasion during the last ice encroachment, an unfavorable period, when man might be expected to move from, rather than into, such a territory?

Valid answers to these and other questions are as yet impossible. There is a need of much further exploration; of much further good fortune in locating additional skeletal remains of all periods, but particularly of the latest Mousterian and earliest Aurignacian; and of a new generation of able workers, well equipped, and unhampered by tradition.

The *indications*, for the present, seem however to be the following:

(1) The Penck-Brückner conception of the Ice Age as composed of four distinct periods of glaciation with three well-marked inter-

glacial periods, does not harmonize well with either the paleontological or the human evidence. Both these tend to show but one main interglacial interval, from which there is a gradual progression toward an irregular cold period, after which follows an irregular postglacial. There is no warm fauna that would correspond to the assumed third (Riss-Würm) interglacial. And there is evident no substantial change, such as would necessarily be brought about by a marked alteration in climate, in man's housing and living habits from the Middle Mousterian to the Magdalenian cultural periods.

(2) The Mousterian or Neanderthal phase of man begins toward the end of the warm main interglacial. It is essentially the period

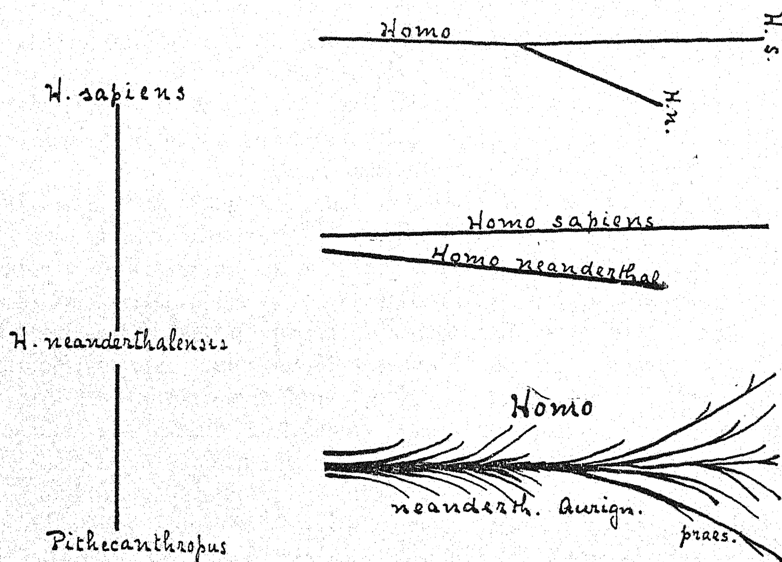


FIGURE 6.—Various conceptions as to the phylogenetic relation of Neanderthal and later man. (Present evidence favors the view represented on the extreme right)

of the cooling stage of the terminal main ice invasion, reaching to, and probably somewhat beyond, its culmination.

(3) During this period man is brought face to face with great changes of environment. He is gradually confronted with hard winters, which demand more shelter, more clothing, more food, more fire, and storage of provisions; there are changes in the fauna which call for new adaptations and developments in hunting; and there are growing discomforts with, it may be assumed, increasing respiratory and other diseases, that call for new efforts and seriously hinder the growth of the population.

(4) Such a major change in the principal environmental factors must inevitably have brought about, on the one hand, greater mental as well as physical exertion and, on the other hand, an intensification of natural selection, with the survival of only the more, and perish-

ing of the less, fit. But greater sustained mental and physical exertion, where not over the normal limits, leads inevitably toward greater efficiency attended by further bodily and mental development which, with the simultaneous elimination of the weak and less fit, are the very essentials of progressive evolution.

Strong evidence that a relatively rapid progressive change, both mental and physical, was actually taking place during the Neanderthal period is furnished by the great variability of the skeletal remains from this time.

(5) But such evolution would certainly differ from region to region as the sum of the factors affecting man differed, reaching a more advanced grade where the conditions in general proved the most favorable; while to many of the less favored groups disease, famine, and warfare would bring extinction. All these agencies are known to science to-day; only they acted with more freedom of old when social organization and mutual aid were at a low level.

(6) With these processes it is conceivable, if not inevitable, that toward the height of the glacial invasion the population decreased in numbers, and that the most fit or able-to-cope-with-the-conditions group or groups eventually alone survived to carry on.

Here seems to be a relatively simple natural explanation of the progressive evolution of Neanderthal man, and such evolution would inevitably carry his most advanced forms to those of primitive *H. sapiens*.

(7) The physical differences observable between Neanderthal and later man are essentially those of two categories, namely: (1) Reduction in musculature—that of the jaws as well as that of the body—with consequent changes in the teeth, jaws, face, and vault of the skull; and (2) changes in the supraorbital torus of the order known well to morphology as progressive infantilism. For both these categories of changes there are later parallelisms. Further reduction of teeth, jaws, and the facial bones has taken place since Magdalenian times, and is now going on in more highly civilized man, of whatever racial derivation; while infantilism is commonly accepted as an explanation of the differences of the negrillo from the negro, and for the greater average reduction of the supraorbital ridges in the negro than in the whites. It would be illogical to deny the probable instrumentality of these agencies in men of an earlier period.

(8) Anthropology is thus confronted with the following conditions:

Neanderthal man is of a primitive physique, appears to have ended by a sudden and complete extinction, and to have been replaced by *H. sapiens*.

But there has been discovered no previous home of this *H. sapiens*, nor any remains whatsoever of his ancestors; and, if he coexisted

with Neanderthal man, it is impossible to understand why he did not prevail sooner, or why he did not mix, or, above all, why he left no cultural remains of his existence.

On the other hand, this same Neanderthal man is now known to show wide morphological variation, leading in the direction of later man; and there are individuals among later men, even to this day, who show transitional features. This might be explained by an original common parentage of the two strains; or by an intermixture of the Neanderthal stock with the succeeding *H. sapiens*; or by a development, evolution, of the former into the latter.

(9) A critical examination of the known facts does not favor the assumption of a far-back common parentage and early Quaternary separation of *H. neanderthalensis* and *H. sapiens*, for lack of cultural evidence of *H. sapiens* and other great difficulties.

It is equally unable to favor a separate origin of the two stocks with subsequent hybridization, for again there is no evidence of the pre-Aurignacian whereabouts and the doings of *H. sapiens*, there is no trace of his ancestry, and knowing his and his descendants' characteristics, it is impossible, as said already by Karl Pearson, to conceive his origin without a Neanderthal-like stage of development.

There remains but the third alternative—which is the evolution of the Neanderthaler into later man. This proposition is not yet capable of conclusive demonstration. There is not yet enough material to decide it one way or the other. But the thoroughly sifted indications appear to the speaker to favor this assumption.

The great current need of prehistory, it may be accentuated once again, is more exploration and more good fortune in discoveries. Meanwhile there appears to be less justification in the conception of a Neanderthal *species* than there would be in that of a Neanderthal *phase* of man.[1]

PRINCIPAL REFERENCES

Adloff, P. Das Gebiss des Menschen und der Anthropomorphen. 8°. Berlin, 1908.

Bayer, J. Mensch im Eiszeitalter. Vol. I, 8°. Leipzig and Wien, 1927.

Boule, M. Fossil Men. 8°. Edinburgh, 1923.

Breuil, M. l'Abbé. Personal communications.

Burkitt, M. C. Prehistory. 8°. Cambridge, 1921.

Fleure, H. J. Some Early Neanthropic Types in Europe and their Modern Representatives. Journ. Roy. Anthrop. Inst., 1920, Vol. L, pp. 12–40.

Gremiackii, A. Podkumskaia čerepnaia kryška i ieio morfologičeskie osobennosti (La calotte du crâne de l'homme de Podkoumok et ses caractères morphologiques). Russ. Antropol. Journ., 1922, Vol. XII, pp. 92–110.

[1] The detailed evidence of the new Gibraltar skull and brain cast, just submitted to the Royal Anthropological Institute (Nov. 1, 1927), goes far to support this assumption.

HRDLIČKA, A. The Most Ancient Skeletal Remains of Man. 2nd ed., 8°. Publ. 2300, Smithsonian Institution, Washington, U. S. A., 1916.

KEITH, Sir A. The Antiquity of Man. 2 vols., 8°. London, 1925.

——— Report on the Galilee Skull: with Researches in Prehistoric Galilee, by F. Turville-Petre. Brit. Sch. Arch. Jerusalem. 4°, 1927, pp. 53–106.

MACCURDY, G. G. Human Origins. 2 vols., 8°. New York and London, 1924.

OBERMAIER, H. Fossil Man in Spain. 8°. New York, 1924.

OSBORN, H. F., and REEDS, CH. A. Old and New Standards of Pleistocene Division in Relation to the Prehistory of Man in Europe. Bull. Geol. Soc. Amer., 1922, Vol. XXXIII, pp. 411–490.

OSBORN, H. F. Introduction to Obermaier's Fossil Man in Spain. 1924.

PEYRONY, D. Personal communications.

PEARSON, K. Side Lights on the Evolution of Man. Univ. Lond. Eng. Lect., Ser. XIII, London, 1921, 27 p.

SALLES, K. Die Cromagnonrasse und ihre Stellung zu anderen jungpalæolithischen Langsschädelrassen. Z. induct. Abstam. u. Vereb'l., 1925, Vol. XXXIX, pp. 191–247.

SARASIN, F. Sur les relations des Néo-Calédoniens avec le groupe de l'Homo neanderthalensis. L'Anthrop., 1924, Vol. XXXIV, pp. 193–227.

SCHMIDT, R. R., KOKEN, and SCHLIZ. Die diluviale Vorzeit Deutschlands. Stuttgart, 1912.

SCHWALBE, G. Der Neanderthalschädel. Jahrb. Ver. Altertsfr. Rheinl., 1900, 72 pp.

——— Kritische Besprechung von Boule's Werk (L'homme fossile de la Chapelle-aux-Saints), mit eigenen Untersuchungen. (Z. Morph. u. Anthrop., 1914, Vol. XVI, pp. 527–610.)

SOLLAS, W. J. On the Cranial and Facial Characters of the Neanderthal Race. Phil. Trans. Roy. Soc. London, 1907, B, Vol. 199, pp. 281–339.

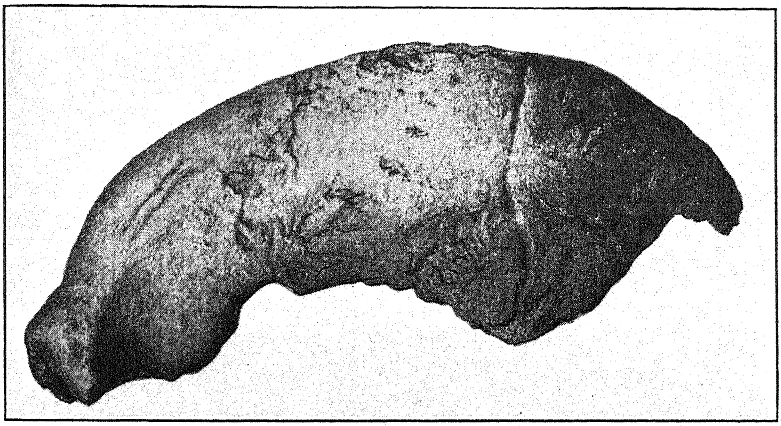
STOLYHWO, K. Homo primigenius, appartient-il à une espèce distincte de Homo sapiens? L'Anthrop., 1908, Vol. XIX, pp. 191–216.

——— Le crâne de Nowosiolka, etc. Bull. Ac. Sc., Cracov, 1908, pp. 103–126.

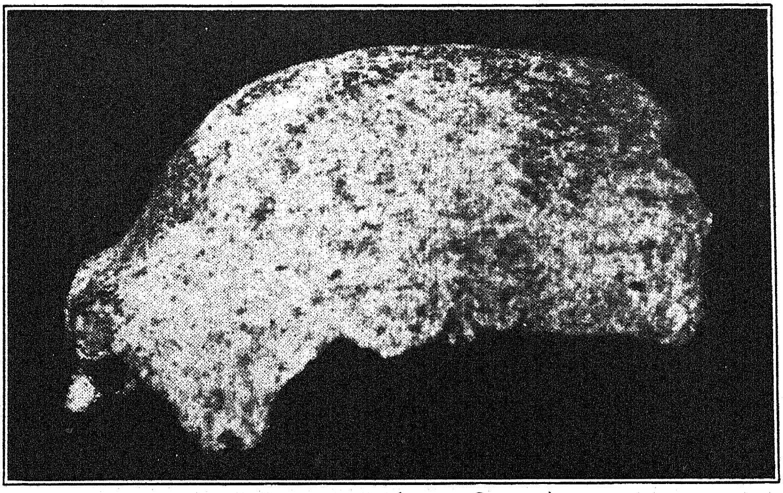
——— Zur Frage der Existenz von Ubergangsformen zwischen Homo primigenius und Homo sapiens. Globus, 1908, Vol. XCIV, No. 23.

SZOMBATHY, J. Die Menschenrassen im oberen Paläolithicum, insbesondere die Brüx-Rasse. Mitteil. Anthrop. Ges., Wien, 1926, Vol. LVI, pp. 202–219.

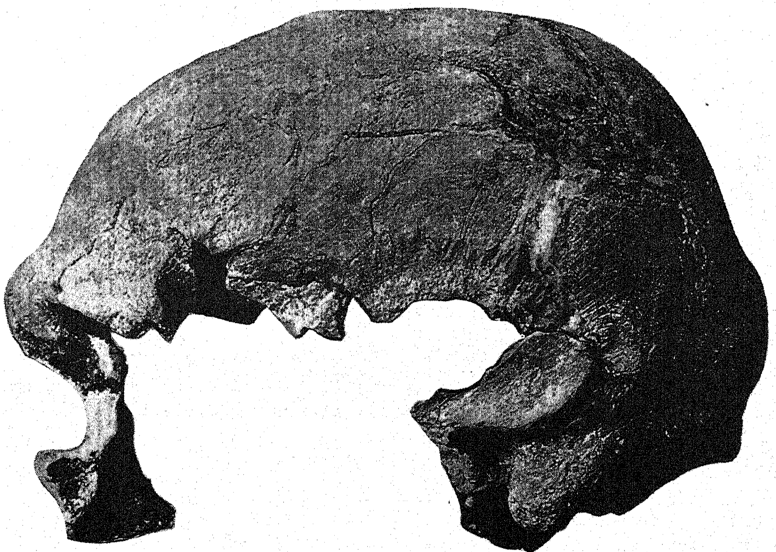
WEIDENREICH, F. Der Schädel von Weimar-Ehringsdorf. Verh. Ges. Phys. Anthrop., Stuttgart, 1927, Vol. II, pp. 34–41; also, Korrbl. d. d. Wiss. u. Tech., 1927, Vol. III, No. 18.



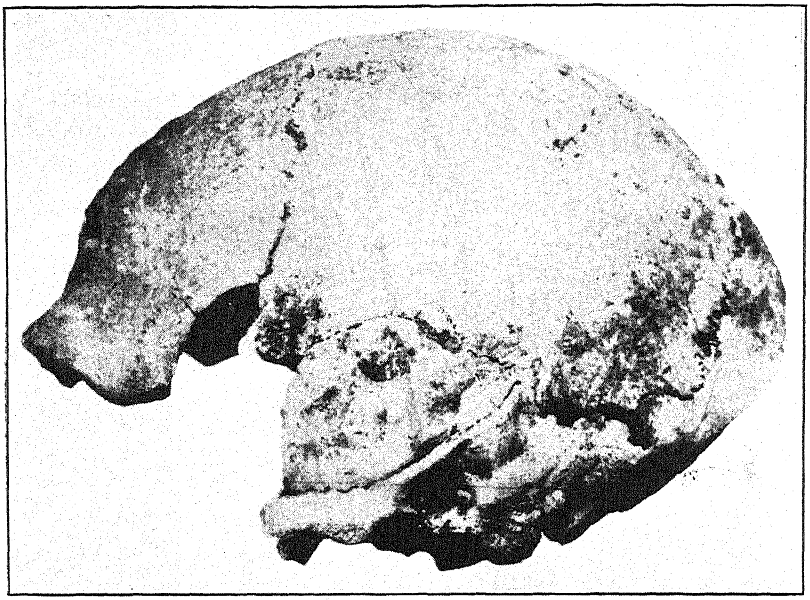
1. MOST (BRÜX) (AFTER HAMY)



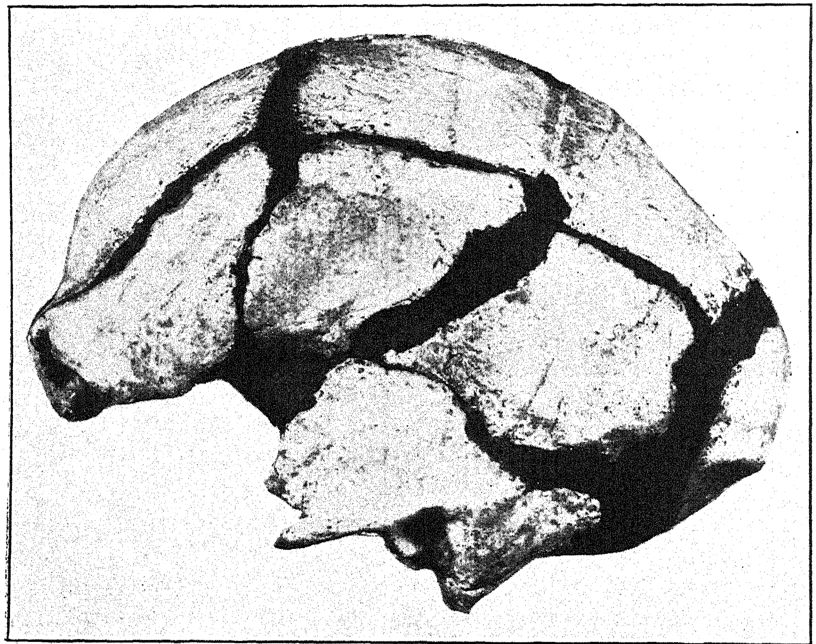
2. PODKOUMOK (AFTER SALLER)



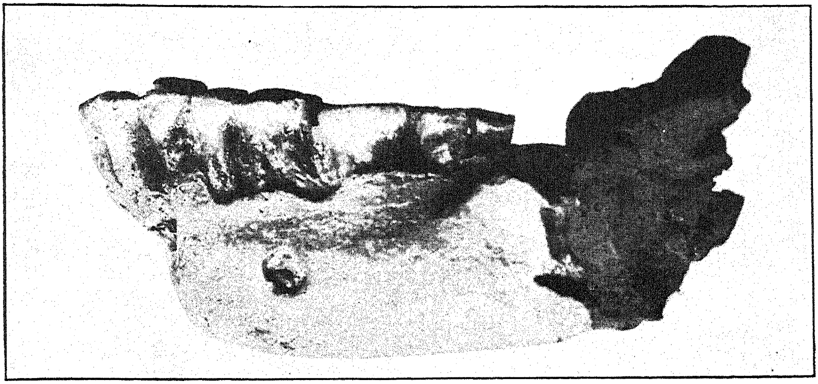
3. BRNO (BRÜNN)



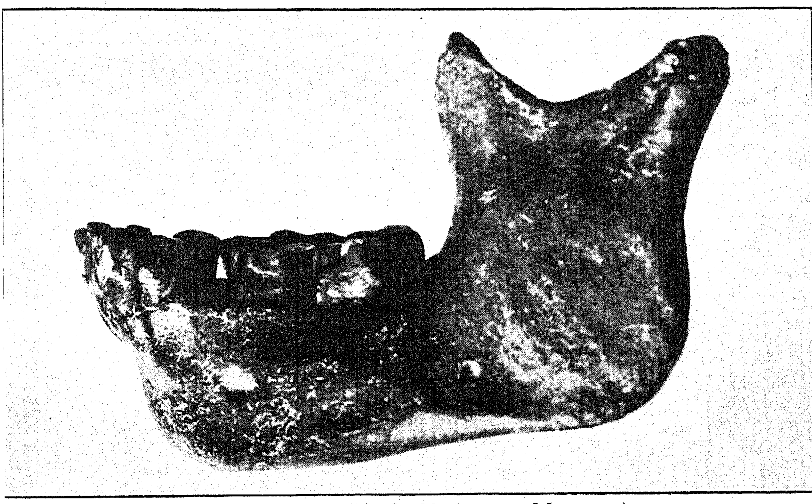
1. SPY (AFTER FRAIPONT AND LOHEST)



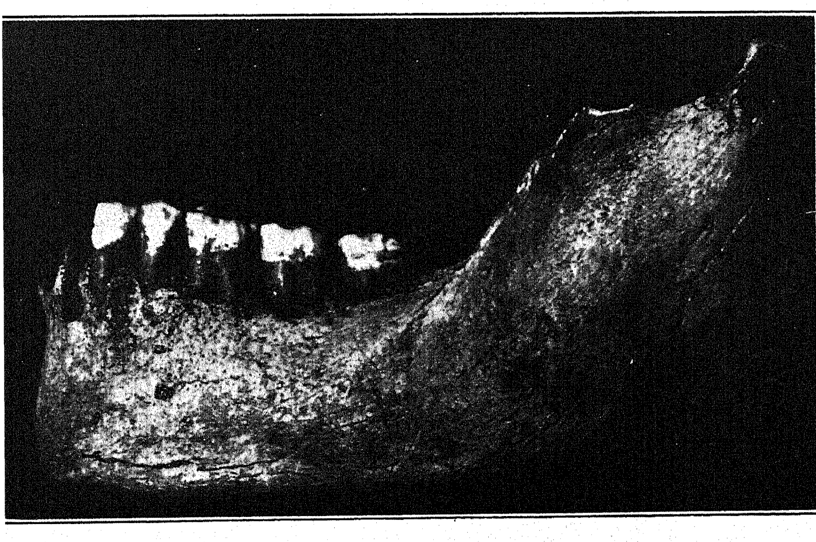
2. EHRINGSDORF, 1925 (AFTER WEIDENREICH)



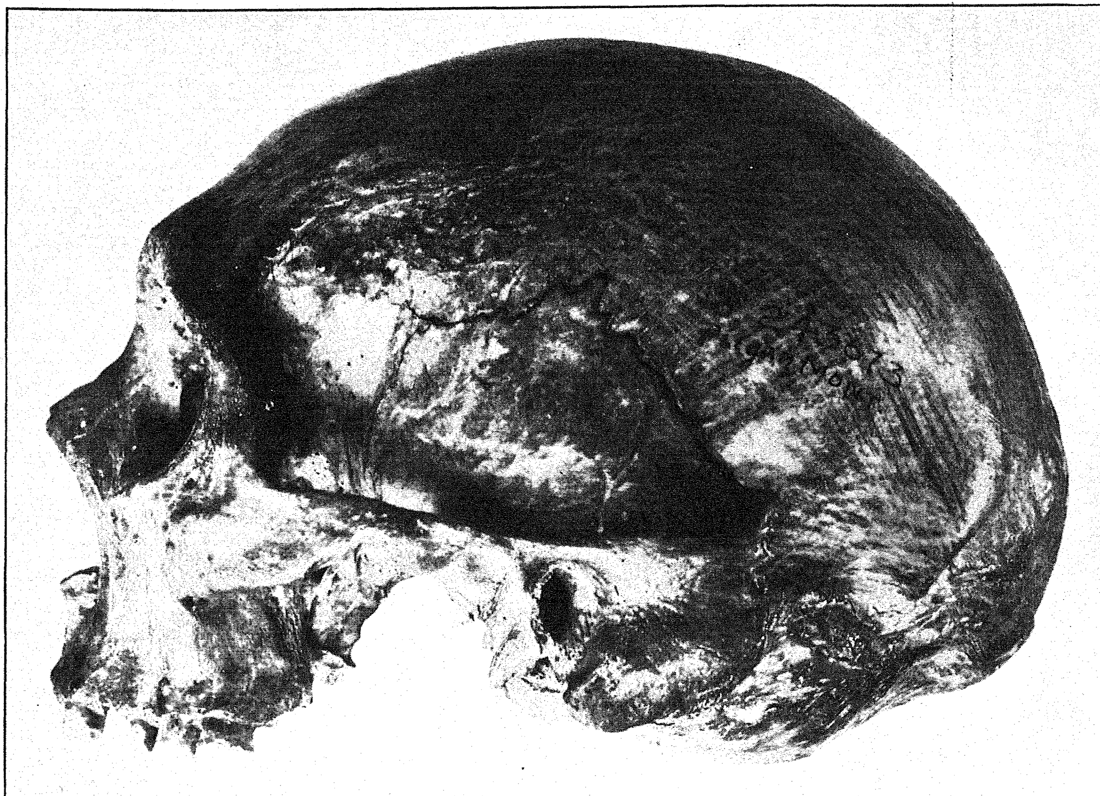
1. EHRINGSDORF (AFTER HANS VIRCHOW)



2. AUSTRALIA (U. S. NATIONAL MUSEUM)



3. LA QUINA (1912) (AFTER HENRI MARTIN)



PIEGAN SKULL (U. S. NATIONAL MUSEUM)

AMERICAN INDIAN COSTUMES IN THE UNITED STATES NATIONAL MUSEUM

By Herbert W. Krieger
United States National Museum

[With 36 plates]

One of the earliest accessions to the ethnological collections in the United States National Museum was obtained by the United States Exploring Expedition under the command of Admiral Charles Wilkes, United States Navy. This collection was gathered in 1838–1842 and includes objects of personal adornment and dress from several of the Indian tribes of the Pacific northwest coast. Another important early accession was the material collected in 1851 by Lieuts. William Herndon and Lardner Gibbon, United States Navy, from Indian tribes occupying the tropical lowlands along the Amazon River and its principal tributaries in Brazil. This collection loses somewhat in value because tribal designations are for the most part not included with the specimens.

The first accession to be received by the Institution from the Arctic was the collection of Dr. Isaac Hayes, which includes objects of dress from the Greenland and Smith Sound Eskimo. The collection of Dr. William H. Dall from the Aleuts and the Eskimo of western Alaska and the Bering Sea coast, and also from the Tinné tribes of the Yukon Valley, was the forerunner of the great collections made from the tribes of the Arctic by E. W. Nelson, E. P. Murdoch, J. H. Turner, and P. H. Ray. To this list of collections from eastern, western, and central Eskimo groups should be added the valuable accessions from the Yukon and Mackenzie River valleys made by Bernard R. Ross and E. A. Preble. Then followed the George T. Emmons collection from southeast Alaska consisting of objects of native dress, blankets, and miscellaneous articles of personal adornment from the Tlingit, Haida, and other Pacific northwest coast tribes. Among the earlier important collections from the same area are those made by Judge James Swan and by J. J. McLean. The collections forwarded to the National Museum by the agents of the Hudson Bay Co. from the Athapascan Indians and other northwest tribes of the upper plateau region are equally important.

In 1868 the collection made by Dr. Edward Palmer in the Southwest began to arrive as the forerunner of a long line of important additions to the national collection of costumes from native American tribes. From 1873 onward there arrived vast quantities of ethnological and archeological material secured by the Bureau of American Ethnology, then under Maj. J. W. Powell, from every section of the United States, but principally from the pueblo region, the latter collection numbering well over 50,000 objects. The Bureau of American Ethnology remains one of the most important sources of ethnological accessions to the national collections.

From California tribes came valuable accessions obtained through the services of Stephen Powers, Livingstone Stone, Lieut. P. H. Ray, C. C. Stewart, J. W. Hudson, and others. The extension of the western railroads to the Pacific coast and the preliminary work which preceded their construction made possible for the first time the accumulation of collections from the interior of the western portion of the United States. The collection made by George Gibbs from the tribes of Washington is typical of several similarly acquired collections. The Hayden survey and numerous other exploring expeditions, including those sponsored by the United States Army within the area of the Great Plains, each contributed many valuable specimens to the Museum collections of costumes and other ethnological material.

Outstanding collections of Indian costumes and associated objects represent most of the geographical areas formerly occupied by the American Indians and are typical of the several culture areas of native America. Outstanding contributors include such names as Maj. J. W. Powell, Emile Granier, George Catlin, James Mooney, Washington Matthews, W. E. Safford, J. B. Steere, W. H. Gabb, H. R. Voth, James Stevenson, W. J. Hoffman, Frances Densmore, F. LaFlesche, William H. Holmes, Walter Hough, R. H. Pratt, and others.

The Museum collections are especially rich in specimens from the Plains tribes. This is attributable to an awakened interest in Indian culture which occurred approximately at the time many of the Plains tribes were first brought into contact with the advancing frontier line. That epoch is now definitely closed, and many objects from the Plains tribes now finding their way into the Museum collections are commercialized products, the income from the sale of which contributes to the support of the western tribes from which they come. Occasionally a valuable collection of costumes from one of the Plains tribes of an earlier decade is received from the family of some officer of the United States Army. These collections frequently include objects of dress formerly belonging to prominent historical characters, such as Chiefs Gall, Red Cloud, Geronimo, Sit-

ting Bull, Moses, and Joseph. One of the more recent accessions of this character is the collection of General Heyl, United States Army, from the Sioux, Cheyenne, and Arapaho. This collection includes the war shields of the famous Chiefs Black Kettle and Crazy Horse.

Types of Indian dress; tailored and woven garments.—The practice of wearing robes fashioned from the tanned skins of animals extends well back into the old stone age in Europe. Possibly the cutting and fitting, or rather, tailoring of skin garments has in the Old World an equally respectable antiquity. Woven fabrics, however, are a more recent product of man's inventiveness and accompany such advanced arts as the practice of agriculture, domestication of animals, and the invention of some form of the loom.

The American Indian from early times possessed a knowledge of weaving which he expressed in several ways, as in the making of baskets, the weaving of nets and cloth. Not all Indian weavers of baskets or makers of nets knew how to use a spun yarn in the weaving of cloth on a simple frame or some more advanced form of the loom. Practically all tribes fashioned nets of plaited basketry splints or of twisted cord. The making of baskets was not practiced by the tribes of Arctic America except in Alaska nor by those of the northern woodlands and the western plains.

The weaving of cloth and the wearing of the products of the loom have a much more restricted distribution, being limited to the tribes occupying the Pacific northwest coast, the region south of the Colorado River, Mexico, Central America, and the South American highlands west of the Andes Mountains. Tribes occupying the tropical lowlands of northern South America east of the Andes Mountains had a knowledge of weaving and of spinning cotton yarn, but these tribes belong to a geographical environment where but little clothing was necessary, and consequently the art of weaving obtained but little headway.

The tanning of the skins of animals and the shaping of such skins into the form of tailored garments likewise had a limited distribution in native America. Indian tribes of the plains west of the Mississippi, of the sub-Arctic in Canada and in Alaska, and the Eskimo possess this art in common with Siberian tribes and the peoples of northern Europe. Throughout the greater portion of temperate America, both North and South, as in Patagonia and in Chile, Indians of both sexes contented themselves with simple and untailored skin robes. In North America this robe was uniformly obtained from the pelt of the bison. We are not referring to the so-called "blanket Indian," who is a product of the white trader, but of Indians as they were dressed before becoming influenced by the white man's trade goods. The comfortable, light-weight Hudson Bay blanket was eagerly sought by the Indian and was readily

obtained by him simply by exchanging a few animal pelts. He was thus enabled to avoid much labor formerly required in the preparing of the skin robes before they might be used as an article of dress.

The distribution in native America of forms of dress, woven cloth, or of tailored skin garments, is but a poor criterion of the antiquity of man in America. Magdelenian man of the old stone age in central Europe understood the use of skin robes, and undoubtedly tailored his skin garments to fit his needs and the dictates of the fashion of the day, but spinning and the weaving of cloth came into existence together with the industries of the new stone age. The presence, therefore, of both forms of dress in native America—that of tailored garments of tanned skins, and of garments of cloth woven from vegetable or animal fiber—is due primarily to several prevailing environmental factors, such as the distribution of animals, principally the bison, deer, and caribou, and of fiber plants, principally cotton. The practice in tropical America of fashioning garments from the beaten inner bark of plants is parallel to a similar practice having a wide distribution throughout the tropical islands of the Pacific Ocean. Climate is probably the most important environmental influence to be considered in any discussion of the forms and materials of Indian dress. The northern tribes generally, and the Eskimo in particular, were the most completely clothed of all native Americans. The particular style of Eskimo dress, however, has been subjected to culture influence coming from northeastern Asia, from tribes with whom the Eskimo has always maintained an active trade.

Northern Indian tribes and the Eskimo cut out and fitted pieces of prepared animal hides. Fur skins, principally those of the seal, and bird feathers were the materials used by the Eskimo of Alaska. These they fashioned in much the same manner as does a modern tailor. The central Eskimo of northeastern Canada depended more on the caribou, an animal related to the Asiatic reindeer recently introduced into Alaska by the United States Bureau of Education, while the northern Indians of Canada and Alaska tanned and tailored the skin of the deer. The hide of the elk was generally considered too thick for use as clothing, while the hide of the bison was valued by the Indian tribes of the Plains more as a robe than as material for working into tailored garments. Like the hide of the elk, that of the bison was considered unsatisfactory as clothing but was tanned and used at times for shirts, leggings, and moccasins.

Sinew from the tendons of animals was used as sewing material, while perforators or awls of bone took the place of needles. The more completely clothed Eskimo also had a higher development of needlecraft than did the northern and Plains Indians. The needlecase of an Eskimo woman contained both needles and thimble of

walrus ivory. Although tailoring was highly developed as an art it does not follow that certain individuals were specially adept in the cutting, fitting, and sewing of skin garments; on the contrary, among the Indians, each individual shaped his or her own garment and sewed it together. The preparation of the skins was considered the work of women. Among the Pueblo Tribes of the Southwest, each individual wove the cloth he or she wished to use as an article of dress. Among the Hopi the bride's trousseau was woven by her prospective husband.

Articles of Indian dress.—For purposes of this article, a detailed description of the clothing of the Eskimo will not be undertaken; attention will be directed to the dress of Indians from the several culture areas of North America. The popular conception of native American dress is that of the Indian of the Plains. The typical costume of tanned buckskin, consisting of a shirt, leggings, belt, breechcloth, and of beaded or quilled moccasins as worn by the Plains tribes has come to be considered typical of all other tribes and culture areas of America in rather much the same manner that the physical features of the Plains Indian erroneously have come to be considered typical of all the Indian tribes of America. Although typical of a large area, including most of the region west of the Mississippi River and east of the Cascades, the Plains type of dress is but one of several of the typical Indian costumes of America.

The dress of the Pueblo Indians of the southwest United States is generally patterned after that of the Plains tribes, but is made of woven fabrics instead of skins, although there are in the National Museum buckskin shirts collected by James Mooney from the Hopi Indians of Arizona, and painted buckskin war shirts collected by J. Walter Fewkes from the pueblo of San Domingo on the Rio Grande in New Mexico. (Cat. No. 175789, U. S. N. M.) By way of contrast, a Hopi shirt, modeled after the pattern of the Mexican poncho, is woven like a blanket but with the addition of a central opening through which the head is thrust. The shirt has rudimentary, loose-fitting sleeves but is otherwise open at the sides. (Cat. No. 23050, U. S. N. M.) Several blanket shirts collected by C. H. Shaw from the Zuñi pueblos of New Mexico also are adaptations of the woven blanket. (Cat. No. 215549, U. S. N. M.)

Woven garments are never cut and fitted as are the skin shirts and other objects of dress of the Eskimo and northern Indian tribes. In the case of the Zuñi and Hopi shirts mentioned above the opening for the neck is a part of the regular weave and the short sleeves are formed by sewing on rectangular woven pieces of cloth. Ordinarily each garment is worn as it comes from the loom, namely, a rectangular, square, or oblong woven fabric.

Materials used in weaving.—Textile garments have been woven from a large number of native vegetable or animal fibers prior to the introduction of sheep into the southwest by the Spanish missions. The wool of the mountain sheep had formerly been used as a yarn by the tribes of the Pacific northwest coast. These tribes also had utilized the hair of the mountain goat and that of an extinct variety of dog. Buffalo hair had been used as a yarn in the valley of the lower Mississippi, where the Natchez also wove a cloth from the fiber of the mulberry. In Mexico and in Central America generally no animal yielding an available supply of hair or wool existed, so that the native use of cotton as a textile fiber prevailed. Even in Peru, where the wool of the llama, vicuna, and alpaca was widely utilized, the weaving of cotton cloth prevailed. We see from this that the utilization of cotton as a textile fabric exceeded that of native wools derived from the pelts of animals. Cotton lends itself readily to spinning and was cultivated to some extent throughout the entire weaving area of Central and South America.

Fabrics of bark.—Indian tribes of the Pacific Northwest coast, and of the Pueblo and Central American areas fashioned garments from bark. The bast fiber was either plaited, as in basketry, or was beaten into a thin sheet, sewn together, and painted much as were the skins of animals farther north. Cedar bark fiber was plaited on the Pacific Northwest coast as far south as the Columbia River and used as articles of dress, matting, and associated objects. Tribes of the Plateau or Rocky Mountain area employed the bark of the sagebrush as a weaving fiber, while the Shoshonean tribes extended this practice far into the Southwest. Farther north the bark of the willow was used as a textile fiber. Tribes occupying the region east of the Mississippi obtained a fiber from basswood bark. Even corn-husks were plaited into several objects of dress by the Iroquois of the Northeastern States. (Pl. 1.) This practice reappears among the Hopi of Arizona in the shaping of circular plaited coils used as a hairdress frame by the unmarried girls. In California and Oregon, also in the Southeastern States, *Apocynum* or Indian hemp and various grasses were plaited or woven.

In Central and South America the number of uses of bark fibers increases only to be supplemented or entirely supplanted in the forested tropical lowlands of Brazil by the use of bird feathers. A bark cloth finishing tool is used by the Guaymie Indians of Chiriqui, in western Panama, in the preparation of bark cloth. The final beating and smoothing of the bark cloth is accomplished by means of this instrument. The handle is of wood, while the working part is a heavy ribbed shell perforated at the apex, where it is secured to the roughly constructed wooden handle. (Cat. No. 272604, U. S. N. M.)

A piece of bast fiber several feet long, collected by Markham from the Tule Indians of the San Blas coast of Panama, consists of the bast of the castilla tree and is much used in making looped hammocks, bark cloth, and breech clouts. (Cat. No. 326823, U. S. N. M.) A similar practice has been observed among the Chocó Indians of the Atrato and San Juan River Valleys of Colombia.

Uses of feathers in Indian dress.—In Mexico and in South America ornamental fabrics were obtained by overlaying cloth with feathers. Throughout native America featherwork constitutes one of the most characteristic developments of Indian dress extending as it does from the Arctic Eskimoan tribes to the scantily clothed Amazonian tribes of South America. Headdresses, skirts, cloaks, and mantles predominate, while feather mosaics were badges of distinction. Mantles of turkey feathers were plaited in the Pueblo area in the Southeastern States along the Gulf of Mexico and eastward to the territory of the Iroquois.

An example of the practical use of feathers may be seen in the birdskin blankets of the Seri Indians of Tiburon Island, Sonora, Mexico. The blanket is made from six skins of the California brown pelican. The pelts of young birds are preferred. Portions of the wing feathers and the breast are sewn together with sinew and the garment so produced forms a complete dress. It is worn about the middle, reaching from the waist, where it is secured by a girdle, to below the knees. (Cat. 174554, U. S. N. M.)

Feather insignia and headdresses were conspicuous among some of the warlike tribes of the western plains. The handsome feathered headdresses with long pennants of eagle feathers that have popularly come to be considered a part of the dress of every Plains Indian were formerly worn only by the most distinguished men. Every feather in such a war bonnet had some significance as a military trophy or a charm and had to do directly with the personal prowess of the wearer. It is stated that the gift of an eagle feather by some individual entailed upon the recipient of the favor the performance of a feat of bravery. The Dakota Sioux were especially addicted to this custom. An ordinary Indian brave was generally entitled only to a simpler headdress. Indian women were by custom not permitted to wear feathers in their hair.

Owing to the perishable nature of the material, most of the evidences of artwork in feathers have disappeared from the northern continent; but, on the authority of old historians and the testimony of a few precious examples still remaining, it is certain that these were used from one extremity of the continent to another. The Virginia Indians made robes of turkey feathers. All the Plains Indians, the hunting tribes, decorated themselves with gorgeous flowing head plumes, and many of the California tribes used feathers

in profusion for the adornment of their most precious basketry. From Mexico southward throughout the Tropics, where gorgeous plumage was in abundance, the Indians made use of feathers for decorating their persons, and ancient Mexican sculptures show that in prehistoric times featherwork of the most elaborate kind was in use. Many specimens of garments in which the patterns were worked out in brilliant feathers are recovered from the ancient tombs of Peru. In the collection shown in the National Museum featherwork is illustrated by the striking war bonnets of the Plains Indians, and by headdresses, plumes, body ornaments, and textiles of various South American tribes. That most of the native tribes appreciated brilliant colors and harmonious effects and were skillful in utilizing the aesthetic resources of the plumage of birds, are amply apparent from these exhibits.

Native culture and Indian reservations.—The student of Indian dress likes to consider the Indian as occupying a distinct geographical environment with its corresponding culture area. Actually, the day is past when such a study may be undertaken in situ. The process of relocating entire Indian tribes upon lands set aside for their use by the Government began as early as 1786. Removal of the Indian from the lands traditionally his hunting preserves, was based in part on peacefully executed treaties and in part on removal by force. The establishment of Indian reservations has in the history of our country amounted to a temporary reserving of specified lands from settlement and the holding of such lands in trust for the Indian occupant. As the Indian is now a citizen of the United States and is allotted an individual holding of land, it is but a question of time when the policy introduced by Carl Schurz, Secretary of the Interior under President Hayes, of weaning the Indian from his native culture and of absorbing him into the body of American citizenry will be entirely accomplished. The Reservation will then have become a closed chapter in the history of the Indian, and acculturation to American modes of dress a completed process.

Influence of the trader.—The first permanent English colony in changed for corn and other Indian products such as tobacco. From extinction by the energy and resourcefulness of Capt. John Smith who engaged in trading with villages of the Powhatan confederacy on the James River. Articles of European manufacture were exchanged for corn and other Indian products such as tobacco. From that time on and continuing up to present times, the advent of the trader and missionary has profoundly influenced native culture. Native costume became modified over a vast area of America by the copying of European dress and the use of traders' wares. Knowledge of prehistoric and early historic primitive textiles has been derived from impressions of fabrics themselves that have been pre-

served by charring in fire, by contact with copper, or through protection from the elements in caves. Our knowledge concerning the costumes worn by the tribes living in the eastern portion of the American continent is deficient because of the early abandonment of tribal costumes and native adoption of white man's dress. Data for several culture areas east of the Mississippi are therefore almost altogether historical.

Dress of the eastern Indians.—In the case of the Virginia Indians, the only source of information is the meager description left by Smith and a number of drawings, now preserved in the British Museum, made by the artist John White, of the Roanoke colony. Aside from the simple buckskin garments, dressed skins of animals and certain coarsely woven cloaks, sometimes tastefully embellished with turkey feathers, were used in cold weather.

In respect to their ceremonial life, industrial arts, political and social organization, the Indian tribes of the southeastern United States rank among the highest of the tribes north of Mexico. Weaving of cloth, however, was limited. The warm climate of the Gulf States and the influence of the example of Antillean and South American tribes with whom a certain trade relationship was maintained may have retarded the development of the weaving of cloth. The absence of any staple textile fiber also tended to make their clothing inferior and scanty.

The use of a buckskin shirt, overshirt, leggings, breechcloth, moccasins, belt, and turban is the characteristic dress of the Seminoles, a typical Gulf State tribe of historic times. Formerly, the Gulf tribes wore a robe, waist garment, and occasionally moccasins. In the Museum collection a lay figure of a Seminole chief is shown dressed in a chief's costume consisting of leggings of buckskin with shirt and coat of many-colored calico. A girdle around the waist with long fringes, moccasins of buckskin, and a helmet-shape cap with heron plumes complete the attire. He carries a tomahawk of European manufacture, an article which became very popular as an object of trade in colonial times.

The Florida Seminoles, now living in the Everglades, belong, with the Creeks, Choctaws, and Chickasaws, to the Muskhogean family, who formerly occupied the Southern States east of the Mississippi River. The unremitting bloody conflicts with the white settlers were brought to an end in 1838, when the Seminoles and their kindred were forcibly removed to the Indian Territory; those that remained fleeing to the Everglades.

Costumes and objects of dress now in the National Museum from the Eastern Indians may be placed in one small exhibit case. The material is therefore entirely inadequate for purposes of study.

The Chippewa inhabit the northeastern woodlands of the United States where abundant timber and bark can be procured for construction of canoes, houses, and implements. No aboriginal costumes of the Chippewa exist, as the tribe has been in contact with civilization for several hundred years. The Chippewa to-day tan excellent buckskin which formerly was used by them for clothing. They also weave belts, sashes, and other objects from yarn on a simple upright frame and make excellent bags decorated with beadwork in floral designs. (Pl. 2.)

Dolls.—The little figure of a Chippewa infant in the Museum was dressed by a Chippewa woman of the White Earth Reservation in Minnesota. It shows the costume of the Chippewa since the traders came among them. The purpose of the fitted cap was to keep the child's head in good shape. The little hoops with yarn lattice had a curative use. It is said that a child with a cold was required to expectorate through one of these hoops and that its cold was cured in this manner. The little velvet bag contains the cord of the child who died in 1890 and who was a son of the woman who dressed this figure. Such a bag was always fastened to the cradle of an infant to insure its health and welfare.

A shawl was laid over a Chippewa cradle to protect the child's head from cold in winter and from the sun in summer. This cradle was a comfortable and convenient way of taking care of babies, especially when the tribe was moving from one place to another. Many of the articles in the exhibit of the Chippewa (pl. 2) were collected by Frances Densmore.

Dolls are in use among all the tribes of the American aborigines from the Eskimo of the North to the inhabitants of Tierra del Fuego. They seem to be divisible into two classes—those which portray the common life, through which children are taught the arts and habits of the tribe, and those of a more sacred character, which lead up to the tribal religion. In the accompanying Plates 25, 26 are exhibited dolls of a more practical character. In each example the dress and accessories show the customs and activities of the people represented. The Eskimo lead with respect to great variety and abundance of dolls, also in the realism of their dolls. Dolls are interesting as showing the costumes of the various tribes.

Cradles.—In the Arctic region the Eskimo women carry their infants on their backs inside of their warm fur clothing. (Pl. 5.) From the southern boundary of the United States through middle America and southward, infants are carried upon the person of the mother, but rarely in frames. On the contrary, in the temperate regions of Canada and the United States the babe is fixed in a frame which is in harmony with the climate and materials. In the country of the

birch the bark cradle is in vogue. On the Pacific Coast various kinds of basketry are used to hold the infants. On the Plains a framework supporting a hood of rawhide is attached to the cradle so that if it falls the infant will not be injured. The inventive mind of the Indian mother in each region has been equal to the emergency.

The cradle of the Sioux (pl. 27) with its peculiar frame and hood is a modification of the more ancient and simple form, and is adapted not only to the carrying of the child upon its mother's back, but also for attachment to the pommel of the saddle. The beadwork, in its material, is derived from the whites, but the style of the ornamentation is purely aboriginal.

Footgear.—Environmental influences are again noticeable in the use of waterproof boots by the Eskimo. Buckskin moccasins with rawhide soles are fashioned by the Indian tribes of the Plains, plateau, eastern woodlands, Yukon-Mackenzie, and Southwestern areas, while the California and Pacific Northwest coast tribes go barefooted. The California Indians did not need footgear, while the Northwest coast tribes found the use of moccasins impractical in their moist climate. The tribes of the arid and hot Sonoran region of northern Mexico, and the tribes of Central America generally used a simple sandal instead of the more elaborate moccasin.

It appears that the sandal was worn mostly in the weaving areas of Mexico and South America, although the tropical forested lowlands of eastern South America and the West Indies and of the southern Gulf States were occupied by Indian tribes not using the sandal. In the region formerly ranged by the American bison (buffalo) west of the Mississippi, also in the temperate plains area of South America the skin moccasin was used. The tribes of the eastern woodlands used a soft-soled moccasin while the Plains tribes used a sole of stiff rawhide. The soft-soled moccasin is of one piece, while the hard-soled moccasin consists of two pieces. The uppers are of a softer, tanned skin and are sewed with thread of sinew to a hard rawhide sole cut to fit the foot of the wearer but also cut according to the prevailing tribal style. War parties could be trailed by marks left in the dust by such tribal peculiarities in moccasin shaping as the cut or form of the toe section. The Arapaho, Ute, and other Tribes of the southern Plains fashioned a boot-like style of moccasin legging, related to that of the Apache of the Southwest, such as may be seen in Plate 17. Some of the northern tribes of Canada and of Alaska made a form of moccasin leggings of soft tanned skin somewhat like those of the eastern woodlands tribes.

Dress of the Algonquian-Iroquois area.—The eastern woodland area extends from the Atlantic Ocean to and beyond the Great Lakes. The northern group of this area between the Great Lakes

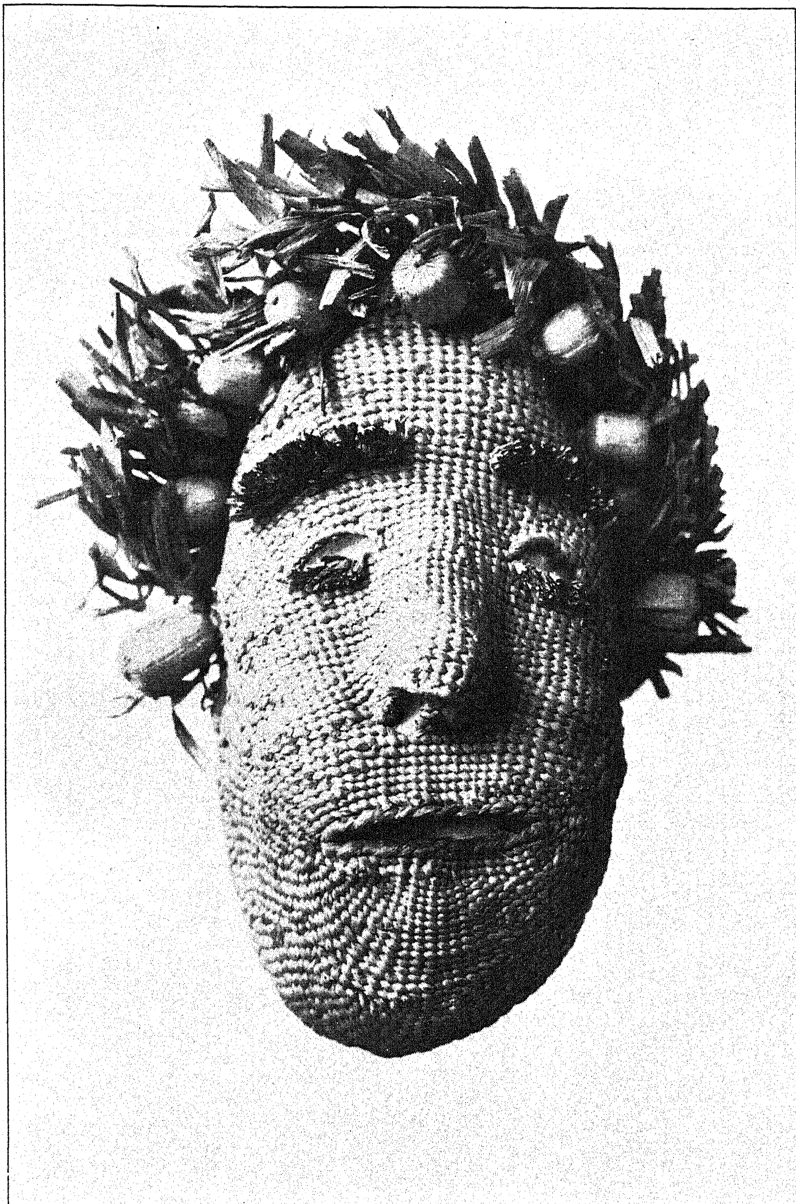
and Hudson Bay and eastward includes the Nascapi of Labrador on the north, and the Cree and Montagnais of eastern Canada. The tribes occupying the region surrounding the Great Lakes, such as the Menominee, Ottawa, Wyandot, Neutral, Chippewa, and other central Algonquian tribes, dress in skin clothes, but the northern tribes as the Montagnais and Nascapi more fully utilize the skins of animals in their dress and resemble the Eskimo in the ensemble of their costume. The men of the northern tribes of this group have a shirt coat, long coat, trousers, leggings, moccasins, and turban. Both men and women of the more southern group, that is, of the central Atlantic coast, wore a cloak, waist garment, moccasins, and possibly a breech cloth, while the western tribes about the Great Lakes had a more complete wardrobe. The man wore a robe, long dress shirt, long leggings, moccasins, bandolier bag, and belt. The women clothed themselves in a long dress shirt, short leggings, moccasins, and belt. The Arctic representatives of the Algonquian stock wore a long coat, open in front, short breeches, leggings, moccasins, gloves or mittens, and a cap or headdress. Women of this region withstood the cold garbed in a robe, shirt dress, leggings, moccasins, belt, cap, and sometimes a shoulder mantle.

In the region surrounding Lake Winnipeg lived the Cree Indians of the Plains and the Plains Chippewa. These were divergent groups of the larger Algonquian stocks occupying the eastern woodland area. Their dress resembled more that of the Plains Indians than that of the woodland tribes speaking their language.

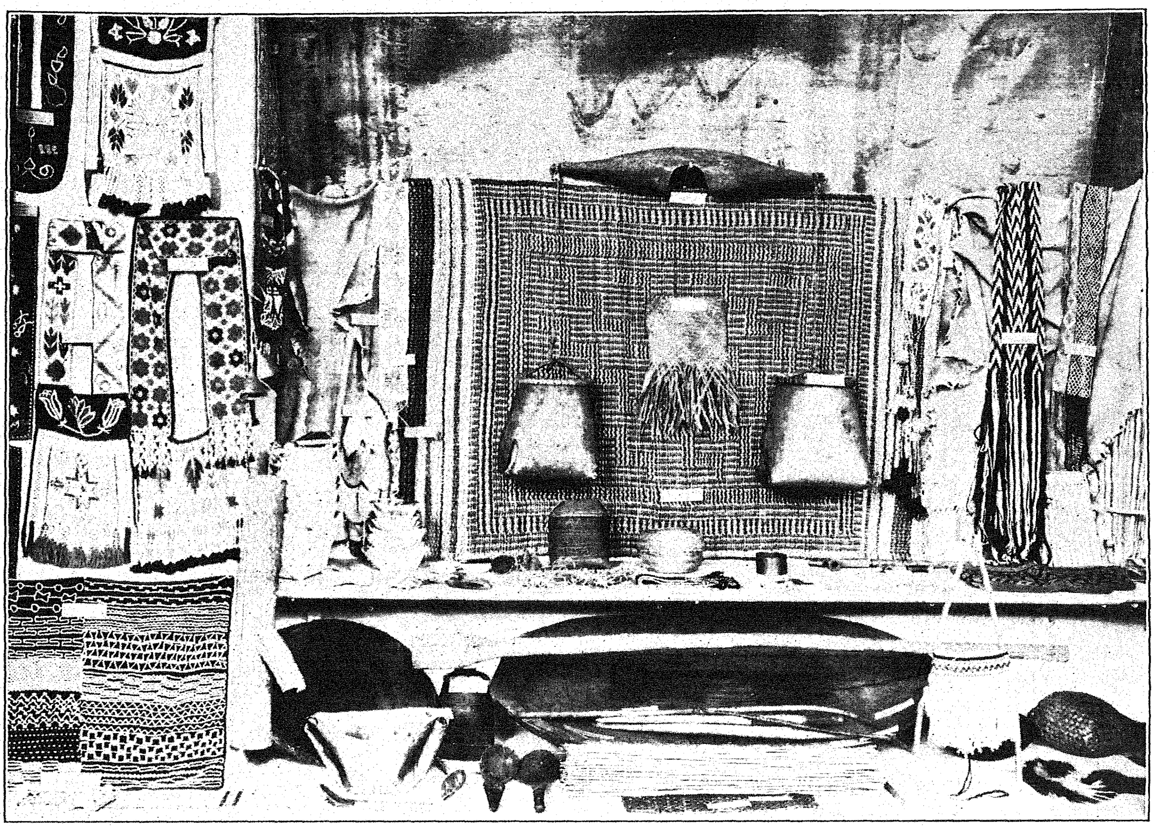
The Montagnais Indians are typical of the North Atlantic culture area. They are of the Algonquian family and occupy Labrador as far north as Ungava Bay. They live by hunting and fishing. Their dwellings are of skins, not sewed together, but laid on frameworks of poles and held down by trunks of small trees leaned against them outside and by stones piled around the base. The Montagnais dress in deerskin robes, quite like those of the Eskimo, their neighbors, but well made, and decorated with paint rather than embroidery.

The Indians of Labrador and their neighbors, the Eskimo, are in comparatively close contact, and the painted skin dress of the former is shown in the case (pl. 3) with the fur costume of the latter. The Indians use very large, almost elliptical snowshoes (pl. 3), and in their transportation, employ long toboggan sleds and canoes of birch bark.

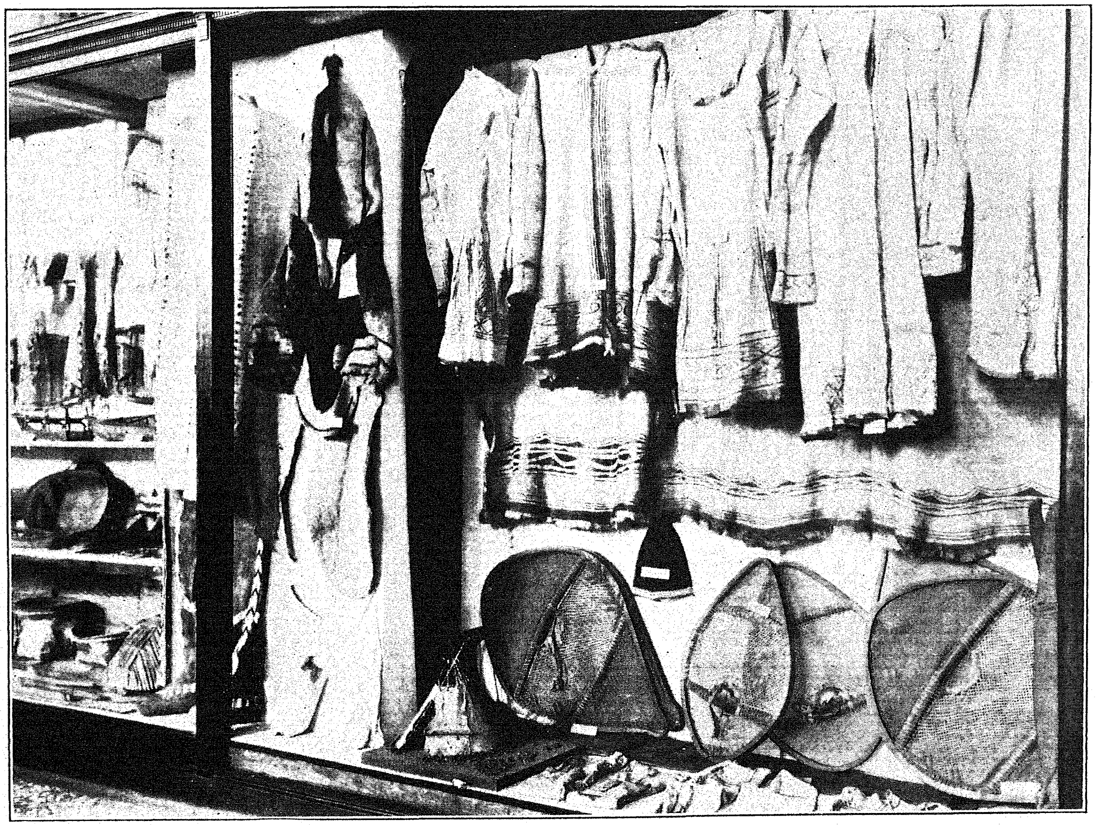
Indians of the Yukon and Mackenzie River Valleys.—The Tinné live in the northernmost extension of timber toward the Canadian Arctic. They dwell in the interior and come in contact with the Eskimo, who live on the northern coasts, and with the Indians of southern Alaska and northern British Columbia. They wear tanned



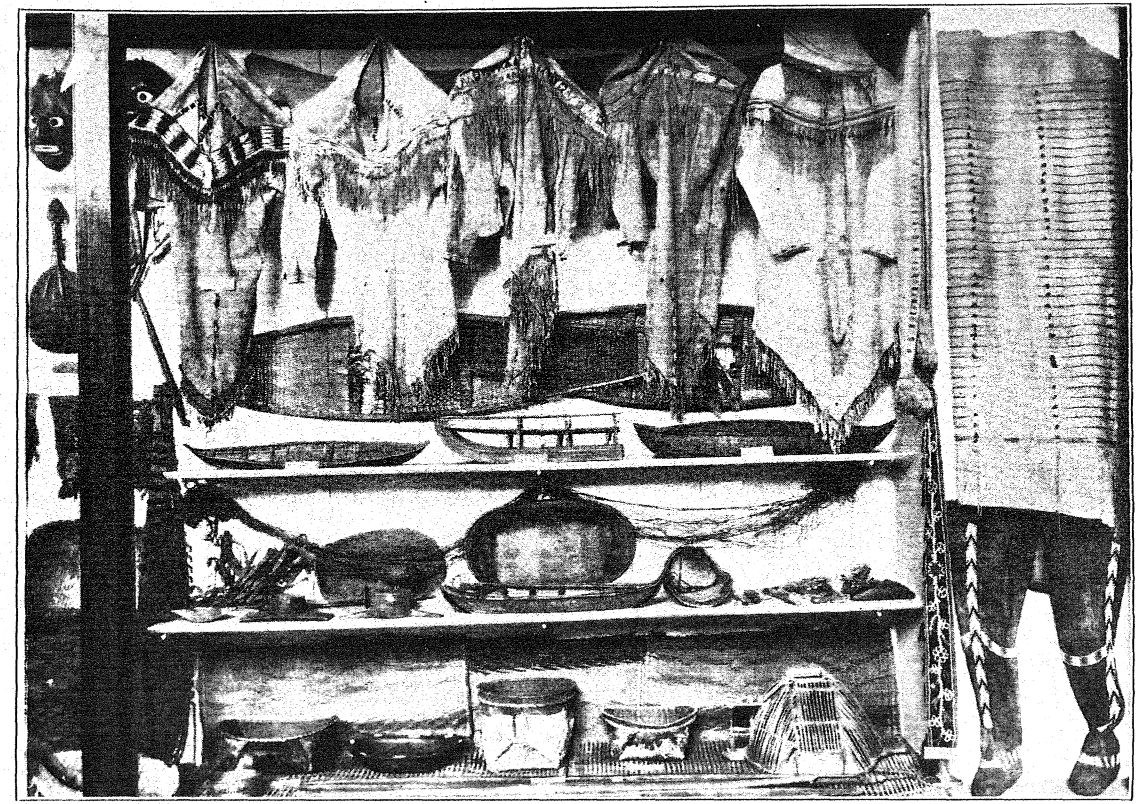
CORN HUSK MASK OF THE IROQUOIS INDIANS



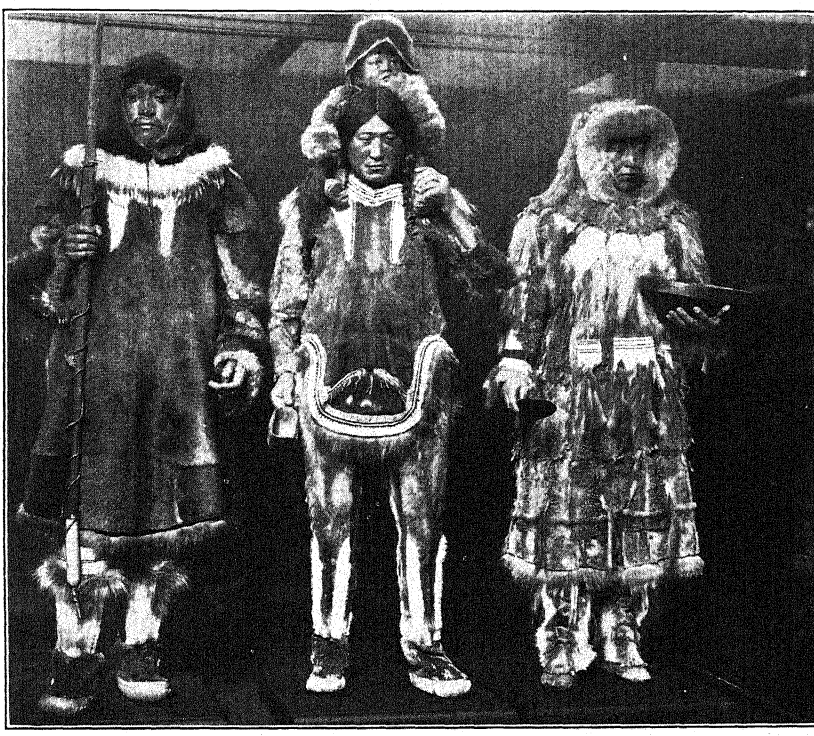
CHIPPEWA INDIAN EXHIBIT IN THE U. S. NATIONAL MUSEUM



MONTAGNAIS INDIAN COSTUMES, LABRADOR

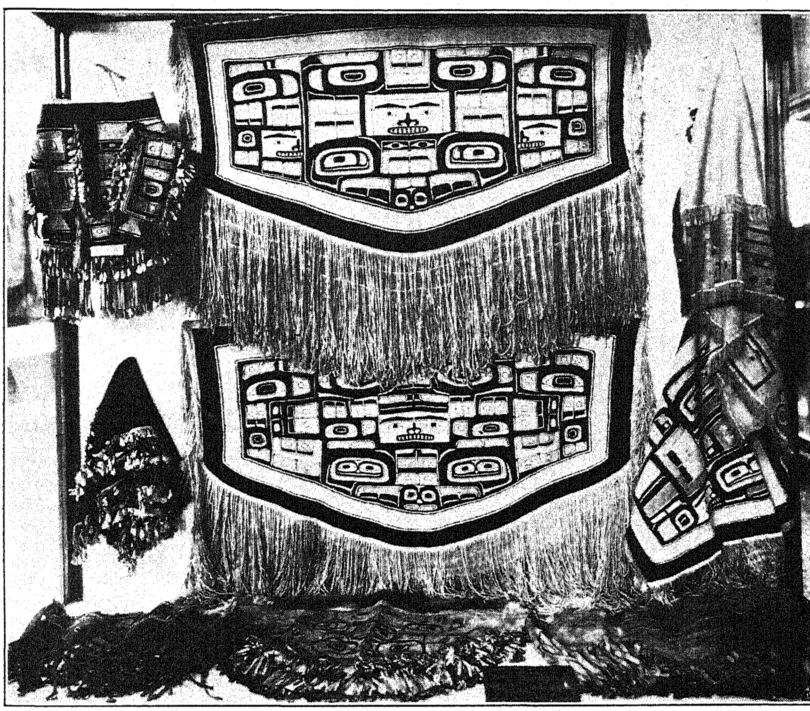


TINNÉ INDIAN COSTUMES AND ARTS, WESTERN CANADA

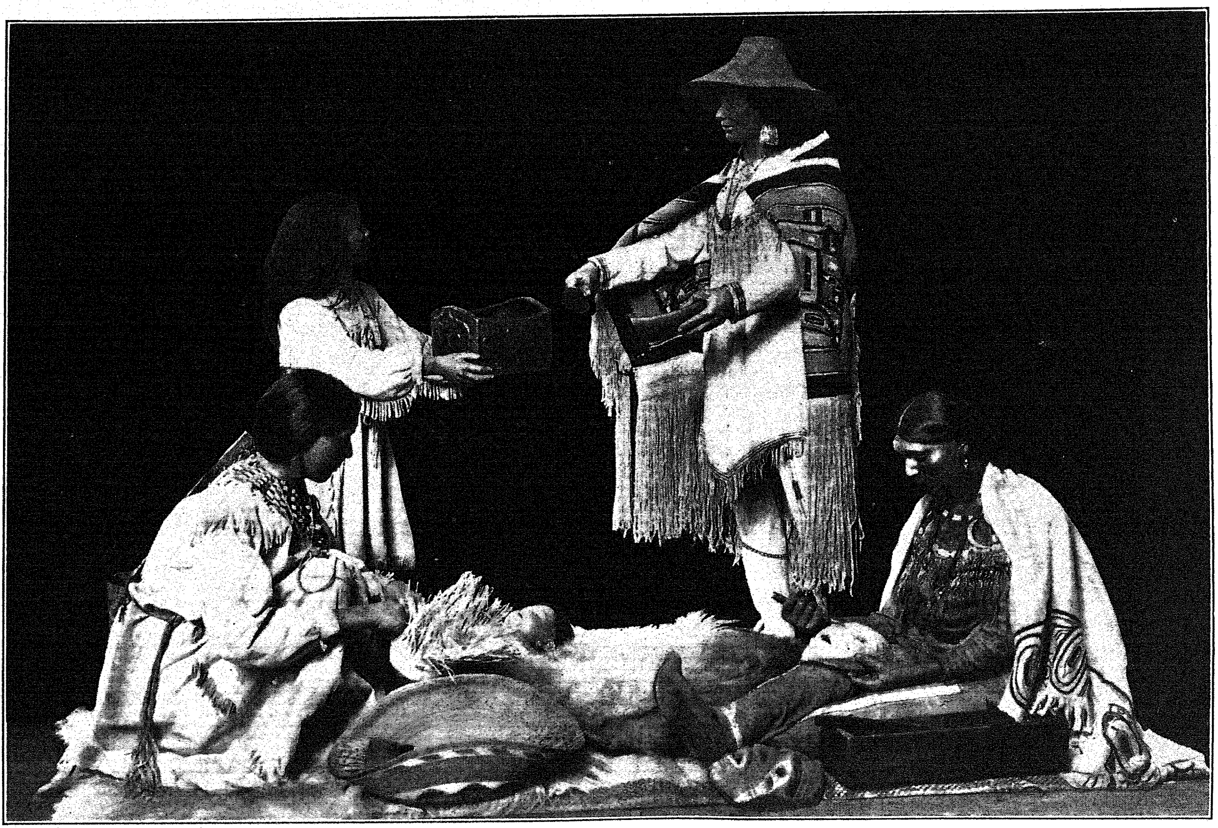


WESTERN ESKIMO COSTUMES

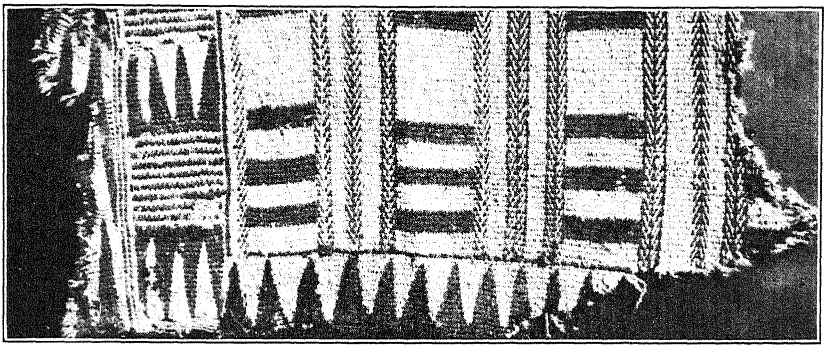
EASTERN ESKIMO COSTUMES



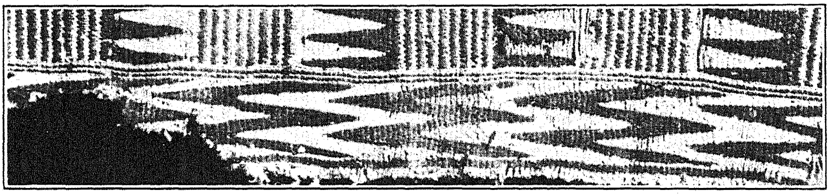
CHILKAT INDIAN BLANKETS AND KILTS, ALASKA



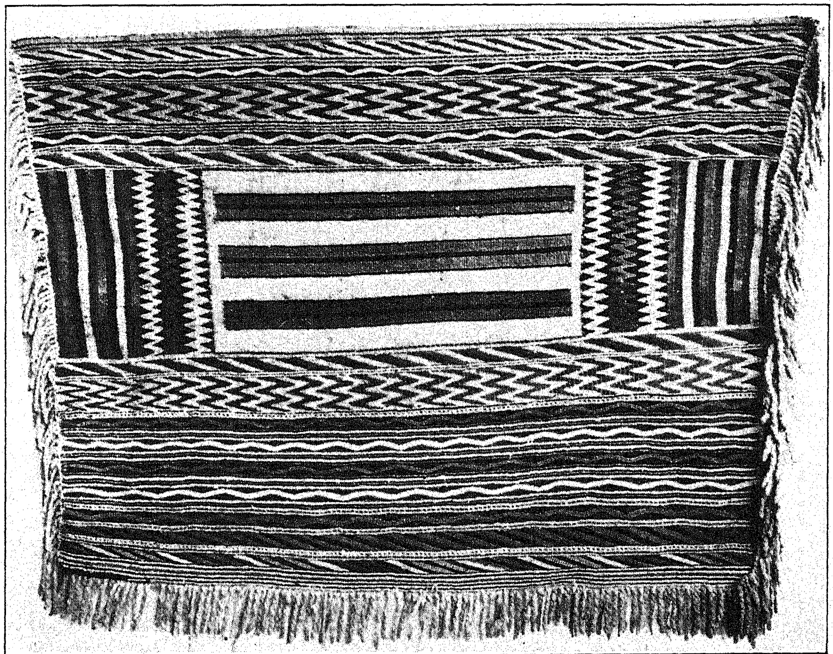
CHILKAT INDIAN GROUPS, SHOWING COSTUMES



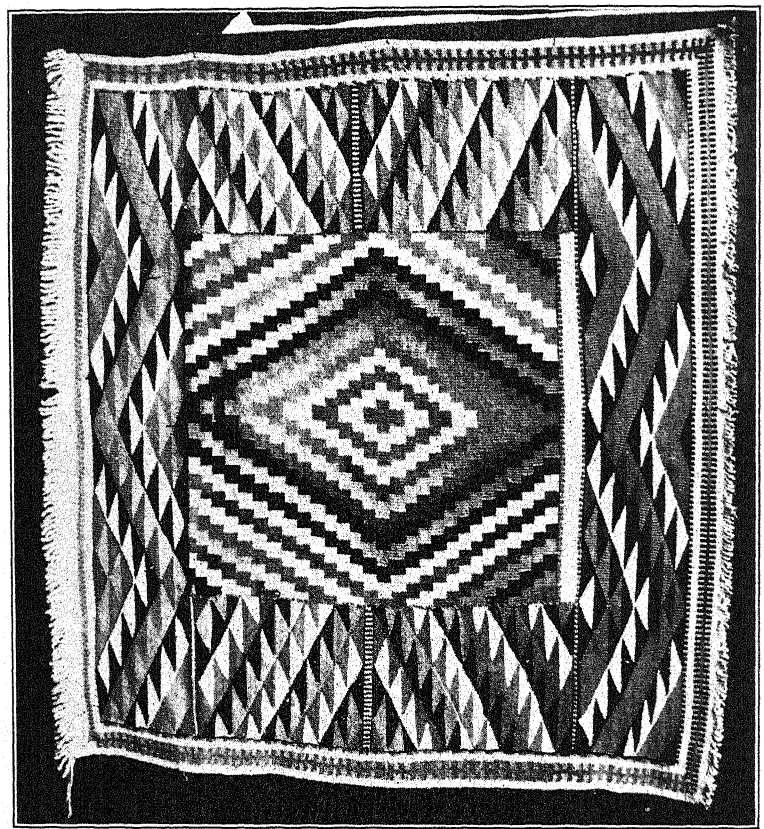
A. SALISH INDIAN BLANKET FRAGMENT



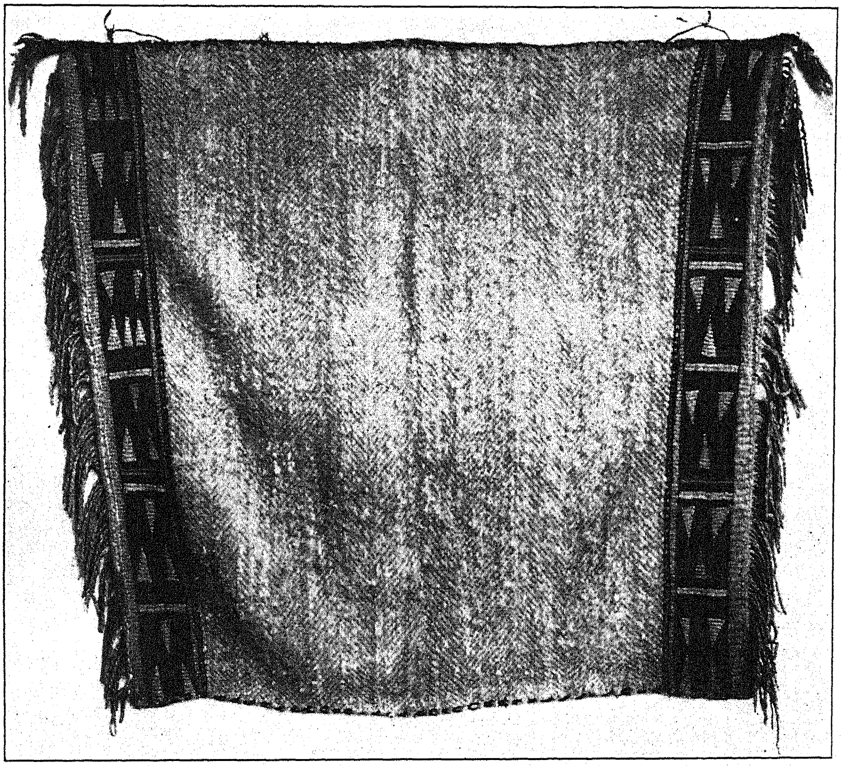
B. SALISH INDIAN BLANKET FRAGMENT



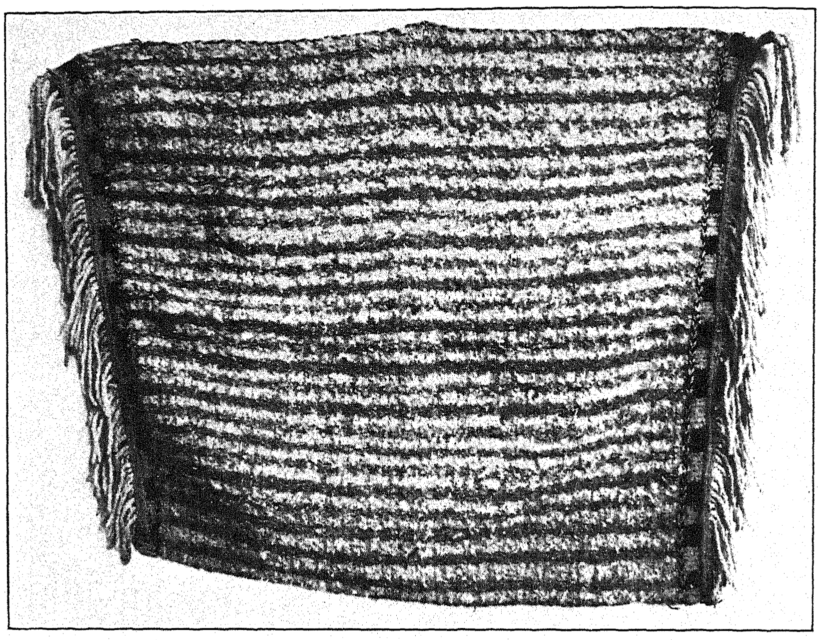
C. SALISH INDIAN BLANKET, WASHINGTON



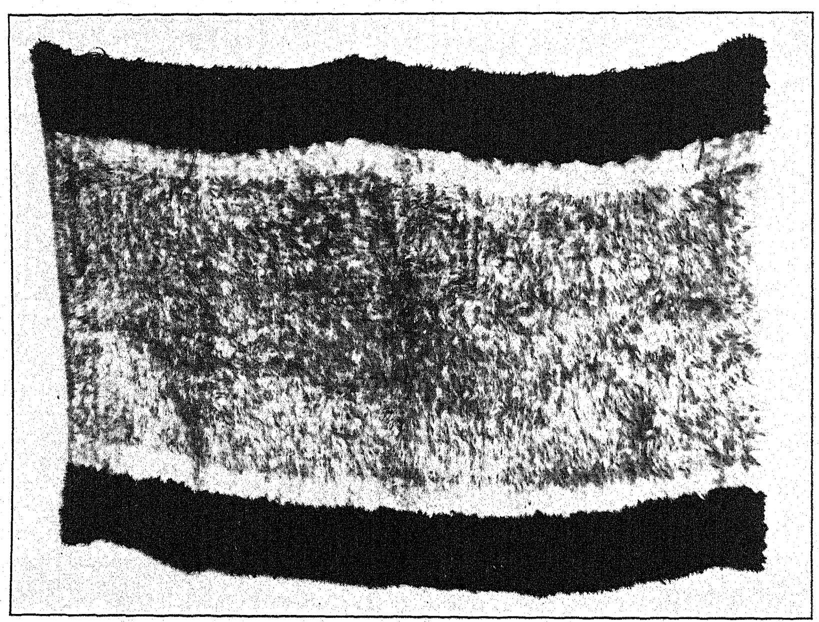
SALISH INDIAN BLANKET, WASHINGTON



BLANKET CAPE, SALISH INDIANS OF WASHINGTON



A. SALISH INDIAN BLANKET, WASHINGTON



B. MAIDU INDIAN FEATHER BLANKET, CALIFORNIA

skin clothing and moccasins, decorated with quillwork and beads (pl. 4), but in winter they move about in snowshoes.

The northern tribes of the United States from Maine to Washington and the Indian tribes of Canada except along the Pacific Northwest coast used the snowshoe in some form. In the extreme West a hoop is bent into round or oval form and the least possible amount of lacing in coarse rawhide forms the footing. But around the Great Lakes and eastward the Canadian forms are continued southward. In all of these the lacing of the toe, the heel, and the footing is in hexagonal weaving and usually in rawhide thongs cut very fine with steel knives. Formerly, before the fur trade was stimulated by the French and the Hudson's Bay Co., the lacing of the snowshoe was much coarser throughout this area. Along the northern border of the Eastern States the frame is square in section, flat, square or rounded in front, and tapering at the heel. In a few examples there is a slight turning up of the toe, after the Canadian fashion. Finally, the snowshoe has become modified for sport and hunting, in one variety resembling the Labrador wide frame and in all other varieties following the Indian patterns. (Pl. 3.)

The northern Athapascan tribes occupy the greater portion of western Canada and the interior of Alaska. The Athapascan linguistic stock, to which the Tinné Indians belong, occupies the most extensive area of any single linguistic family or cultural group in North America. The dress of these Indians is an adaptation to the environment in which they live and consists of tanned and tailored skin garments. The men wear a shirt coat, a breechcloth, hat or hood, and legging moccasins, while the women wear a long shirt coat, belt, and legging moccasins. (See pl. 3.) The caribou supplies these Indians with skins for clothing and tents, although many other available fur-bearing animals are utilized. Among this group, as among all northern tribes, the snowshoe is in general use.

A typical group of the northern Athapascan Indians are the Loucheux of Canada, who live east of the Mackenzie River. For many years they have been in contact with the Hudson Bay Co., who have used the men as hunters for catching fur-bearing animals. In summer they dress in reindeer skins and ornament themselves with bird quills, dentalium shells from the Pacific coast, and trade beads and worsted from Europe. Most of the costumes exhibited were collected by B. R. Ross and R. McFarlane. (Pl. 4.)

Dress of the Eskimo.—The necessity for protection against the cold of the Arctic is evidenced in the wearing of mittens and gloves by Eskimo and other northern peoples of native America. Although the dress of several northern Athapascan and Algonquian tribes approximates that of the Eskimo, the latter alone succeed in occupying the Arctic fringe or coastal strip of North America. Their

habitat extends from Greenland and the islands north of Hudson Bay on the east to the isolated islands of Bering Sea on the west.

The so-called western Eskimo inhabit the shores of the northern seas from the mouth of the Mackenzie River around Alaska to Mount St. Elias on the south. Their habitations, as well as their mode of dress and living, vary according to the animals on which they depend, and the contact they have had with other races. In Plate 5 are seen a man, woman, and child from the Mackenzie River district dressed in caribou skins, and a woman from Bristol Bay clad in marmot skins. The Norton Sound Eskimo have been under instruction of Russians and Americans for more than 100 years, and their mode of dress has become much modified. The Eskimo who inhabits the coast and a portion of the lower river valleys of Alaska have found means to adapt themselves to the requirements of the rigorous climate. Two articles of dress illustrating this adaptation are snowshoes and snow goggles. Snow goggles are shaped from wood or walrus ivory and have narrow slit openings for shutting out much of the glaring sunlight as reflected from the snow fields. Even with this protective device snow blindness is not unknown among them.

Among the central Eskimo who live on the area between Hudson Strait and Baffin Bay the clothing of men and women is made from skins of seal and deer. It consists of outside and inside trousers, jackets, boots, and inside boots made of light deerskin or birdskin. The inside boots take the place of socks, which, among several of the western Eskimo groups, are fashioned from native grasses. The jackets of the women have hoods attached to them.

The eastern Eskimo inhabit Greenland, the shores of northern Labrador, and of Hudson Bay, adjoining. In the Museum installation (pl. 6) will be seen a young woman from southwestern Greenland, her dress resembling that of a Lapp; a man from eastern Hudson Bay, with his harpoon; a woman with her babe, from Ungava Bay, Labrador; and a woman from northern Hudson Bay in garments of reindeer skin. In the first named the people have been under instruction of Moravian missionaries many years. The women are dressed in aboriginal costumes of reindeer fur, little modified by outside influences. The loose, roomy garments correspond with those figured by the early voyagers. The showy costumes ornamented with fine sewing of reindeer hair and applique of colored leather, together with the robes of eiderdown are particularly attractive. The Greenland Eskimo have been in contact for many years with the Danish rulers and settlers, which has especially modified the art with which they construct their clothing, but not the form of the clothes themselves. (Pl. 6.)

Dress of the Pacific Northwest coast tribes.—The area north of California lying between the Pacific coast and the Cascade Mountains was formerly inhabited by Indian tribes possessing many similar culture traits centering around the fishing industry. Quite aside from any influence exerted by other tribes upon the natives of southeast Alaska and the Puget Sound area together with the outlying islands of British Columbia, there remains the tremendous effect of environment upon their daily life. The extremely moist climate of the so-called Alaskan panhandle is well known. At Ketchikan, near the southern boundary of Alaska, the average number of days during the year with an appreciable amount of rainfall reaches a total of 235. The warm northwest Pacific current reaches the shores of southeast Alaska, moderating the climate far above that of the mainland east of the costal mountain ranges.

Two of the most characteristic elements in the dress of the Indians of the Pacific Northwest coast—the use of waterproof clothing and the practice of going barefooted—are directly connected with the peculiar climate under which they live. Waterproof mats of plaited cedar bark, and a raincoat of grass with the shaggy unfinished elements on the outside, and with an opening cut out of the center like a poncho for the head, were worn by men and women. As moccasins of skin or tanned leather are of little use in such a continually moist environment all footgear was dispensed with except in winter, and by the more northern Tlingit tribes. A basketry hat (pl. 8) was worn to shield the wearer against the rain. With the exception of the basket hat of the Ute, Californian, and other Pacific coast tribes, and the hood as worn by the tribes of the sub-Arctic, no other tribes on the American continent employed hats or a head covering of any description except ceremonially and for decorative purposes.

The tribes represented by the fabrics shown (pls. 7, 8) include the Tlingit and Haida of southeastern Alaska and many of the related tribes of British Columbia. From this exhibit, specimens in rigid materials, such as basketry, are omitted, and the collection is devoted entirely to soft and flexible objects. The possession of the Rocky Mountain goat for animal staples and of the wild hemp for vegetable staples enabled these tribes to produce most satisfactory results. The dress of the North Pacific tribes was made of skin, woven bark, native woolen textiles, and traders' goods, ornamented with beaks of birds, hoofs, fur, and claws of animals, or buttons and beads procured from the white man. The ordinary costume consists of a blanket or bark-mat mantle, belt, breechcloth, leggings, and moccasins. The ceremonial costume was varied, but the parts usually consisted of headdress mask, neck, and breast ornaments, skirts with rattles, and leggings. (Pl. 8.)

The exhibit of Tlingit and Haida costumes in the National Museum consists of large ceremonial blankets of goat's wool, robes of tanned deerskin bordered with quilled fringe and superb decoration in color, splendidly painted; dance aprons trimmed with fur and fringed with deer-hoof tinklers; and woven dance apron and capes trimmed with puffin beaks. (Pl. 7.)

For ceremonial occasions and to protect the body against the cold of winter the Northwest coast tribes wore a robe of skins or of woven fiber. This robe was rectangular and was wrapped about the body under the left arm and over the right shoulder. The legs from the knees down remained uncovered.

The women tied aprons of shredded bark around the waist and a cape of woven cedar bark covered them from neck to knees.

The weaving of the Chilkat, the most northerly of the Tlingit tribes, attracts attention because of the materials used and the oddity of decorative design. Wool of the Rocky Mountain goat, either in natural color, or dyed black, yellow, or green was used combined with threads of the inner bark of the cedar. The native loom consists of a single bar supported on two forked stakes. No machinery is needed for shifting the warp or driving the weft, the woman's fingers taking the place of these. Indeed, it is simply a method of twined basketry in soft material, producing figures as in Gobelin tapestries. The Chilkat type of weaving is shown here by a blanket, a coat, and a ceremonial apron, into which are woven with excellent effect figures of symbolic animals. (Pl. 8.) The light-green color was produced by permitting copper to corrode in urine, while the yellow came from a variety of tree moss; black dye was produced by boiling the bark of the hemlock.

Women as well as men had their bodies tattooed by introducing soot under the skin. Tattooing marks were applied principally to the arms and legs. Women carried labrets, or wooden disks, at the center of their lower lips. As was the practice among most Indian tribes of North America the men's hair was worn long and the beard was eradicated. Among them as with most tribes among whom there existed a strong social organization a remarkable development of ceremonial life is noticed. On ceremonial occasions they covered their bodies with oil over which was daubed a mixture of sparkling sand, paint, and mica. White down was also employed to enhance personal beauty on religious occasions.

Dress of the tribes of the Washington-Oregon coast.—Among the tribes of this area, men wore a robe, a headband, and more rarely a shirt, coat, leggings, moccasins, and a breechcloth. Women also wore a long shirt, dress, apron, and rarely leggings, breechcloth, and moccasins.

If we include as typical of Northwest coast area all tribes dependent on the sea for food and possessing a conventionalized totemic art, it becomes possible to extend Northwest coast culture along the coast of Washington and Oregon up to and including the northern portion of California. If the Tlingit, Haida, Tsimshian, and Kwakiutl are typical tribes of southeast Alaska and of British Columbia, the Salish tribes of Vancouver Island and the Nootka of the lower Frazer River valley may be considered typical of the more southern groups. The Tahltan and other Athapascan tribes of the interior of British Columbia possess an entirely different type of dress resembling more that of the Plains tribes. The Tahltan Indians have in recent years discontinued all their native arts and industries because of changes brought about by the great number of miners who have invaded their territory.

Typical of the textile arts of the Salish Tribes of Washington and the Columbia River region generally is the blanket woven from the hair of the mountain goat. There had developed among the Salish Tribes of the Columbia River region at the time of the first explorations an interesting primitive weaving industry in the hair of the dog and mountain goat. A few specimens of robes and blankets have survived and are of great rarity. They show superior skill in weaving and taste in their decoration with dyed cords and the down of birds. Salish blankets were traded with the interior tribes and were carried long distances from the coast. In some cases other tribes received the credit of weaving these blankets, for instance, the Nez Percé and other Shahaptian tribes who traded with the Salish were believed to be weavers. Salish Tribes wove burden straps of which the warp is of strong hemp, and the weft of goat's wool dyed in various pretty colors. (Pl. 13.) The weaving proceeds always entirely across the warp, but is done in twined work like the weaving of the Chilkat Indians farther north. The Shahaptian Tribes of the Columbia River region wove blankets of rabbit skins. They are likewise represented by their soft carrying wallets in wild hemp and twined weaving, decorated with tasteful geometric figures in overlaying with variously dyed grasses.

A Salish blanket collected by Charles Wilkes (Cat. No. 2124, U. S. N. M.) (pl. 9C), is made by the process of twined weaving, entirely of dog and mountain-goat hair yarns dyed and undyed. The patterns are alike on both sides as in the Navaho blanket. In some cases the weaving follows the design, that is, the warp is inclined at an angle. The pattern is in four divisions, as follows: Across the top are three bands with designs as in the belts; the center is composed of three bands of yellow, margined with black and with a black line through the middle, all on a white field. The white field is flanked by a rectangular area divided into equal sections of bands

and zigzags. The lower portion is in eight bands of serpentine, diagonal, and straight lines. The colors are natural wool, black, dark brown, red, yellow, and blue. One band of red and blue appears to have been derived from the ravellings of European fabrics, the rest are in native dye. The blanket is fringed on three sides, the elements of the fringe twisted and not braided. Dimensions: Width from top to bottom, 50 inches; breadth, 62 inches; fringe, 7 inches long.

Another beautiful Salish blanket from the State of Washington (Cat. No. 1891, U. S. N. M.) (pl. 10), was collected by Lieut. G. K. Warren and accessioned by the Museum in 1866. It consists of dog and mountain-goat hair in twined weaving. The colors are white, red, black, very dark blue, two shades of yellow, and green. The design consists of a central rectangle 32 by 35 inches in terrace pattern with square cross in center. This is surrounded by zigzag bands made up of engaging triangular figures. Two sides are bordered with a band of short lines crossing a center line. The ends have a narrow band of similar pattern. A sewing or embroidery of cord forming a welt borders the upper and lower sides of the rectangular center and on the sides at the junction of the patterned portion with the border band. Dimensions: Sixty-two by 64 inches.

A fragment of a Salish blanket (Cat. No. 177710, U. S. N. M.) (pl. 9A) collected by George Catlin was found among his effects and had been through the various fires befalling his collections of ethnological objects since 1840. The warp of this specimen is a stiff and heavy cord of some fiber not ascertained. The weft is soft pelage of the mountain goat. The colors are dark green, brownish red, black, and white. The patterns are simple, consisting of bands of W shape, comblike, and sets of three horizontal bars divided by narrow stripes of herringbone pattern. The border is of wedges of black and green on white background. This interesting relic is probably from the Lewis collection from the Columbia (Lewis and Clark expedition), which is said to have been acquired by Catlin. Dimensions: 39 by 47 inches.

A blanket cape from the Salish Indians of Washington (Cat. No. 221408, U. S. N. M.) (pl. 11) is one from the collection of George Gibbs or Charles Wilkes. This garment is fringed and bordered at the sides as in Catalogue No. 1894, United States National Museum. The border patterns are in rectangles marked off by horizontal bands, the design being four spindle-form elements side by side in black, white, brown, yellow, and green. The pattern is characteristic of a considerable region focusing in the Salish and whose boundaries have not yet been ascertained. The main field of the blanket is covered with white down incorporated during weaving. The latter is of the twisted or twined type done by hand as in making a twined

basket. The materials are: Dog hair, goat hair, and down. This is a rare and valuable specimen and is in excellent condition. Dimensions: Upper border, 46 inches; lower, 41 inches; width, 45 inches; width of fringe, 7 inches; width of border, 5 inches. On the upper corners are tassels and on the borders are thongs of buckskin for securing the wrap. This blanket may be the No. 675 of the George Gibbs collection described by him as "a cape or shawl of goat and dog hair."

Another blanket cape from the Salish Indians collected by Lieut. G. K. Warren, United States Army (Cat. No. 1894, U. S. N. M.) (pl. 12, A), is a wrap for the body. It is in twined weaving, the materials being dog and goat hair and the down of waterfowl. The upper and lower border are plain and the sides decorated with round braided fringe. The surface of the textile presents a nap of down in alternate horizontal bands of gray and brown down incorporated in the thick structure during the process of weaving. A strip along either side is without down and has a pattern in squares of black, white, red, and green. It is margined by a cording next to the downy portion. Dimensions: Upper border, 41 inches; lower border, 49 inches; width, 45 inches; width of fringe, 8 inches.

A woven belt from the Salish Indians of Washington (Cat. No. 2120, U. S. N. M.) (pl. 13), collected by Charles Wilkes, is of a twined weave in red, green, and natural yarn of the hair of the Salish domestic dog and the mountain goat. The design comprises a central section of horizontal lines in red, green, and white, two sections of zigzags in white and red, and one section like a tree with branches. The weaving was worked both ways from the middle as in many hand-woven belts. The warp forms a long fringe at one end and at the other end the fringe is looped over the warp ends. Braided cords are supplied for tying at the ends. Dimensions: 34 inches wide; 92 inches long; fringe, 19 inches long.

Another woven belt from the Salish collected by Charles Wilkes (Cot. No. 2121, U. S. N. M.), also shown on Plate 13, is similar to the one described above, but appears to be a much older object.

Woven belts from the Salish, also collected by Charles Wilkes, are shown on Plate 13 with the above. The objects are of a fine weave in soft yarn of the hair of mountain goat and dog, in natural color, and dyed red, yellow, dark blue, and light green colors. The edges are bound with drilling of cotton. No device for tying is found at the ends, although the objects were used as ornaments for costume, or, perhaps, as belts. Dimensions: 1½ inches wide; 28 inches long.

Dress of the California-Oregon tribes.—The tribes of California excelled in decorative art, which they applied to almost all objects of use. Examples of costumes and adornment as skirts of pine seeds and braided grass, basketry headdresses, necklaces, and other objects

are shown in the Museum. Californian culture was crude and simple although the art of basketry weaving was more highly developed than elsewhere in the United States, but the weaving of cloth was not practiced.

The Hupa Indians of California had a robe and waist garment on occasion for the men, but moccasins rarely. Old men frequently went entirely naked. Women wore a waist garment and a narrow apron, and occasionally a robe cape like the Pueblo, over shoulders or under arms over the breast. A basket cap was ordinarily worn, and sometimes moccasins. In central California men usually went naked, but possessed a robe, a netted cap, and occasionally a breechcloth, and moccasins. In this area the women wore a waist skirt of vegetal fiber or of buckskin, and a basketry cap. A robe and moccasins were worn on occasion. Necklaces and earrings completed the costume of the women of central California. (Pl. 14.)

Along the Pacific coast and also on the Mexican border, on the Gulf coast, and in the Eastern States generally, the customary woman's garment was a fringe-like skirt of bark, cord, strung seeds, or peltry, worn around the loins. In cooler weather a skin cape was thrown about the shoulders, and in certain tribes a large robe of rabbit skin. The use of such robes was not rare in California but the use of moccasins and of leggings was occasional. Some tribes near the Mexican Provinces wore sandals, a type of footgear having formerly a much wider range of distribution than in historical times. Belts not only confined the clothing but supported pouches and bags. Large pouches of netting were slung from the shoulder.

A headdress and carrying net of the Pomo (Cat. No. 200019, U. S. N. M.) was collected by W. H. Holmes and is now in the Museum collections. It is made of cotton twine, doubled and netted with coarse mesh. The net is gathered into a woven band decorated with shell beads. This band passes across the forehead and rests upon a thick padding. The lower end of the net is gathered into a knot on a toggle of bone. The carrying basket is inserted in the net.

Livingston Stone collected from the Indians living along the McCloud River in Shasta County, northern California, a girdle made of human hair braided into fine sennit and wound into a skein 200 yards in length. The ends of the loop are wrapped with thong covered with split root. The two ends are brought around the waist and fastened with a thong of otter skin. (Cat. No. 17309, U. S. N. M.)

A headdress of the Tulare Indians consisting of whole feathers in the middle and of split feathers around the outside was collected by W. H. Holmes. (Cat. No. 200090, U. S. N. M.) The headdress is typical of the southern California tribes. Whole feathers are

wrapped around the stem with cord and the split feathers are fastened to a continuous cord. These are coiled round and round to make a dense bundle. The whole is mounted on a long skewer or harpoon of wood. Associated with the headdress is a headband of down formed on a cord of cedar bark in the same way that Christmas wreaths are made up, and also a network headband made from the native hemp. The network is first wrapped round the head, then covered with a wreath of down. The staff of the feather headdress is forced between the head and these bands and so held in place.

A feather blanket from the Maidu Indians of central California was collected by Charles Wilkes and is now in the Museum collections. (Cat. No. 2119, U. S. N. M.) This blanket is made from the white, gray barred, and iridescent dark brown feathers of waterfowl applied closely to fiber cord by wrapping around the quill ends of the feathers. This cord is run continuously back and forth and twined with bark cord forming the warp. The corner cords are plaited like the lariats of the northern region. The middle portion of the blanket is of gray barred feathers bordered with white. The outer border is a wide band of dark-brown glossy iridescent feathers. The robe is feathered equally on both sides. Dimensions: Width, 45 inches; length, 63 inches. (Pl. 12, B.)

A Seri bird-skin blanket collected by W J McGee from the Seri Indians of Tiburon Island, Sonora, Mexico, is made from the skins of fully matured California brown pelicans. The entire breast and portions of the wing feathers are used from each bird. As many as 10 skins enter into a complete blanket or robe. The skins are sewn together with sinew. (Cat. No. 174555, U. S. N. M.)

These blankets are complete dresses for both men and women, and are worn about the middle as short skirts secured about the waist by suitable girdles, or thrown about the shoulders as mantles. They are used also as mats or beds. They take the place of the blankets or dressed-skin robes of more northerly Indians.

The whole Pacific coast west of the coastal mountain ranges was occupied by barefooted, scantily clothed peoples. Among these tribes, from the Tlingit in Alaska to the Seri in Lower California, coat and trousers were not worn, the robe of woven hair or of feathers or rabbit skins serving instead.

Dress of the Pueblo Indians.—The tribes of the pueblo region belong to the Athapascan, Shoshonean, Zuñian, Keresan, and Tanoan linguistic families. These various stocks embrace not only tribes living in pueblos, but others like the Navaho and the Apache who do not live in pueblos but have their homes in the valleys and on the plateaus of northern Arizona and New Mexico. These latter Indians were chiefly hunters and therefore did not live in settled communities. They practiced agriculture to a limited extent but were

inferior in this respect to the more sedentary village or Pueblo Indians. They have been called nomads, as they settled where they chose regardless of the claims of the several Pueblo groups already occupying the area. They belong to four linguistic stocks, the Athapascan, Piman, Yuman, and Shoshonean. The Plains east of the pueblo area were traversed by many groups of hunters in search of the bison, also by the Kiowa and Comanche Indians, who raided the less aggressive settlements of the pueblo area and of Mexico.

West of the pueblo area is the barrier of the Colorado and the desert which effectively separated the Pueblos from the Californian tribes and from any influence that might reach them from the Pacific coast. The Pueblos were also separated from the highly cultured native tribes of the valley of Mexico by the desert and hostile tribes of Sonora. Therefore, the only communication with other tribes was by way of the Great Plains. This almost complete isolation served to emphasize the peculiar development of habits of dress peculiar to the Southwest, but with a certain leaning toward the dress of the Plains tribes on the east and that of the Pima on the south.

The dress of the Pueblo Indians has remained practically as it was in Coronado's time in the sixteenth century until recently, when the influences of modern transportation such as railroads and automobiles have brought about a change. Factory made cotton prints have almost entirely replaced the products of the native weaver.

Villages occupied by the Pueblo Indians are divided into two general groups, the Rio Grande Pueblos of New Mexico on the east, and the Hopi and Zuñi on the west. There are minor differences within the Rio Grande area, but these need not be considered here. The eastern or Rio Grande group of Pueblo Indians have within historic times dressed pretty much as do the tribes of the southern Plains. Men dressed in garments of tanned skins which were painted with decorative designs similar to the painted war shirt collected by Doctor Fewkes from San Domingo, one of the Rio Grande Pueblos. At present the woman's dress of the Rio Grande Pueblos of Taos and Pecos is the long skin dress of the Plains type. Long leggings of fringed buckskin and a breechcloth of colored flannel are worn by the men.

The more westerly Pueblos, those of the Hopi in Arizona, and the Zuñi, were dressed, according to early accounts, in aprons or kilts of woven cotton. These kilts had tassels at each corner and resembled the kilts still used on certain ceremonial occasions. The essential garment of the Pueblo man at present is the breechcloth of woven cotton, which falls below the belt before and behind. In general, the clothing for the Pueblo men consists of a blanket or robe of rabbit skin or feathers, a shirt with sleeves, short breeches

partly open at the outer sides, breechcloth, leggings reaching to the knees, moccasins, hair tape, and headband. Women's clothing consists of a blanket fastened over one shoulder and extending to the knees. A small calico shawl is worn over the blanket and thrown over the shoulders. Legging moccasins and a belt are also worn by the women. Snow moccasins of fur are sometimes worn in winter.

Because of the protected situation of the ancient cliff dwellings, the ancestral habitations of the Pueblo Indians, numerous perishable objects illustrating the social and domestic life of the people have been preserved. From these old dwellings, protected as they were under rock shelters, we have recovered yarn, woven cloth, sandals, cord, and basketry in an excellent state of preservation. Some of the ancient pueblo sandals recovered are woven of yucca leaves, either in a diagonal or twined weave. The warp is of yucca leaves, but the woof is cotton fiber. Decorative designs on these ancient examples of footgear are in colors or are applied by the imbrication of basketry materials in loops of twine. The ancient aprons of twine or twisted cord resemble in a way the generalized form of cord apron skirt characteristic of the Pacific coast tribes of historical times. The apron was confined by a girdle but the lower end of the twisted cord was unattached as in the apron of the Hupa. (See pl. 14.)

Dress of the non-Pueblo Tribes of the Southwest.—The Apache and the Navaho are typical examples of the nomadic Athapascan tribes of the Southwest. They are related linguistically with tribes as far north as the Dene of the Yukon and Mackenzie River Valleys of northwest America. Several scattered bands of Athapascans are found in western Oregon and California. The Navaho live in the vicinity of the San Juan and Little Colorado Rivers while the Apache are widely scattered throughout the area. There are four bands of the Apache, known as the Jicarilla, Mescalero, San Carlos, and White Mountain groups.

The non-Pueblo tribes, such as the Apache (pl. 15), dress as do the Indians of the Plains in so far as the men are concerned. The Apache women wear a moccasin having a peculiar shield-like oval extension of the stiff sole in front of the toes. Although the Navaho formerly were dressed like the Plains tribes they now have adopted the costume of the Pueblo Indians. The Mohave and the Cocopa of the Sonora-Gila region have a somewhat different dress. The men wear a breechcloth, sandals, and sometimes a headband, while the women have a waist garment, usually of fringed bark, covering the front and rear. The Pima dress like the Plains tribes, though they formerly wore a cotton robe, waist cloth, and sandals.

24034—29——42

The Hopi of Arizona occupy eight pueblos in northeastern Arizona. They are among the most northerly of the Indian tribes employing the loom, which found its greatest use in ancient Peru. Among the Hopi men wear an apron or breechcloth, over which formerly was worn at times a robe of woven woolen cloth, or of woven rabbit skin, or turkey feathers. Women wore a dress blanket reaching to the knees and fastened over the right shoulder. Moccasins of hides and buckskin are worn, to which are often added leggings of buckskin or sheepskin by the women. The use of a calico shirt and short trousers has taken the place of the ancient costume among the men, while the women continue to wear a dark-blue woolen blanket woven on native looms and fastened with an embroidered belt.

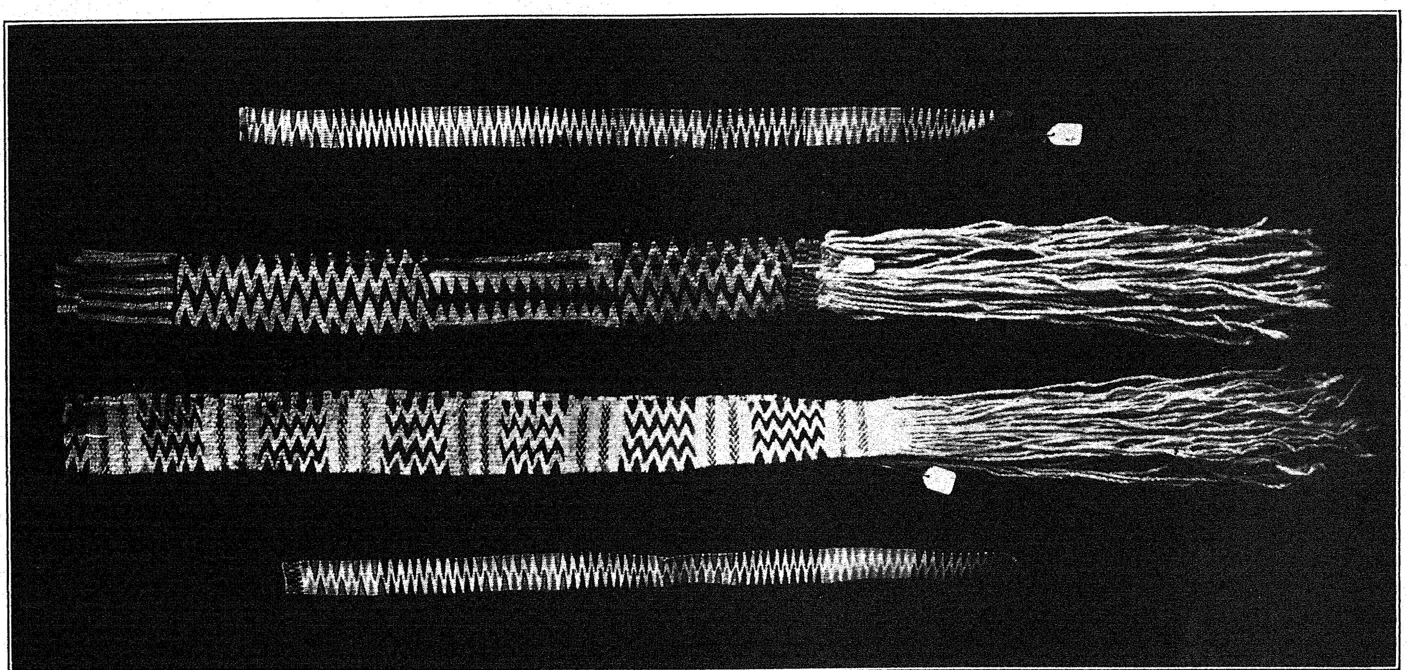
There are exhibited looms for weaving blankets, belts, and sashes, and examples of the work in cotton and wool. Woven and embroidered wedding blankets, sashes, and kilts used in ceremony, and braided sacred sashes are shown. Shoulder blankets, breechcloths, weaving sticks, and plain and figured belts are typical articles illustrating the loom work of the Hopi.

In the weaving of their belts the Zuñi employ a weaving heald made of numerous short sticks placed side by side in a perpendicular position and their ends lashed with buckskin cord to sticks running horizontally. Small holes are burnt midway of the upright sticks to hold the warp threads. In the belt weavers' outfit of the southwestern United States the warp is shifted by a wooden harness and the weft is beaten home by a wooden sword. While engaged in weaving, women sit on the ground, and the loom is shifted instead of altering the position of the body on the ground after the weaving has progressed to a certain stage.

At Zuñi the fiber of the yucca plant was woven into the single garment worn by women at the beginning of the historical period. This garment, reaching from the shoulders to the knees, was fastened over the right shoulder and by a belt worn at the waist. A similar garment of woven cotton cloth was worn by the women of other pueblos. Under the influence of the Spaniards, after the introduction of sheep, this garment was fashioned of woolen yarns and dyed black or blue, but remained otherwise practically unchanged. At the outset of the historical period the cotton used in spinning yarns was grown at Hopi and on the Rio Grande, especially at Cochiti.

Moccasins were originally worn by Zuñi men and women. These had rawhide soles and were fashioned to reach to the knees for winter wear. Women's moccasins at present are equipped with a long legging wrapping of buckskin. A woolen cloth or footless sock is worn underneath the wrapped legging.

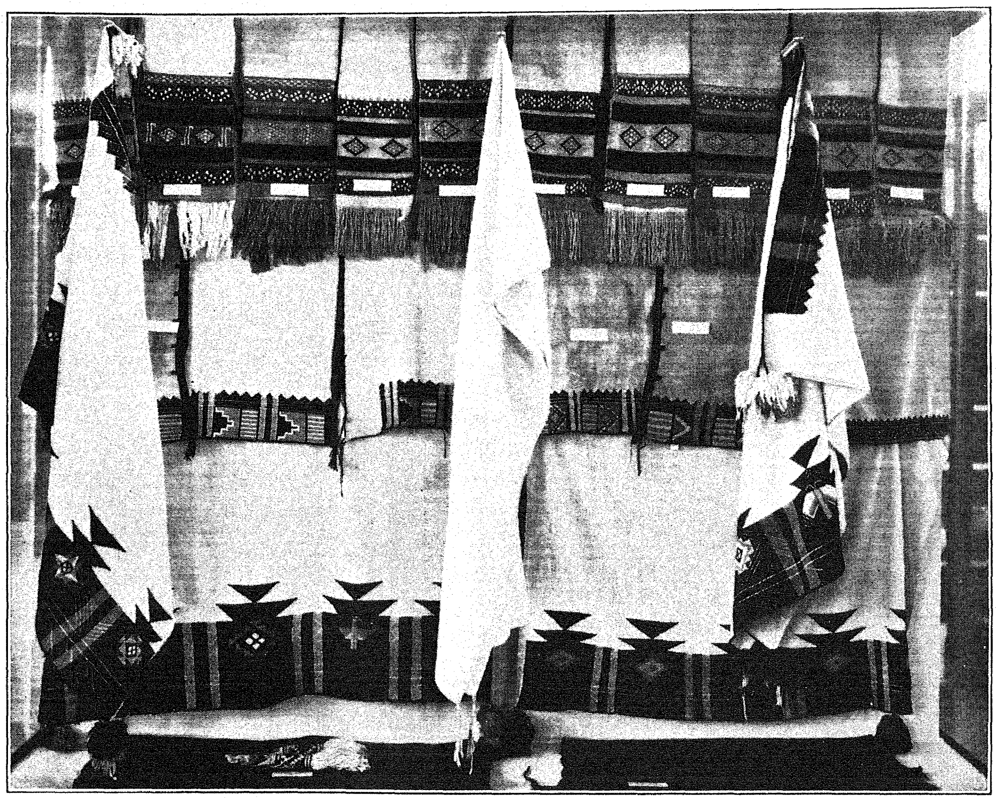
Formerly, the hairdress of Pueblo women was elaborate. The hair was done up above the ears in large whorls over a frame of corn-



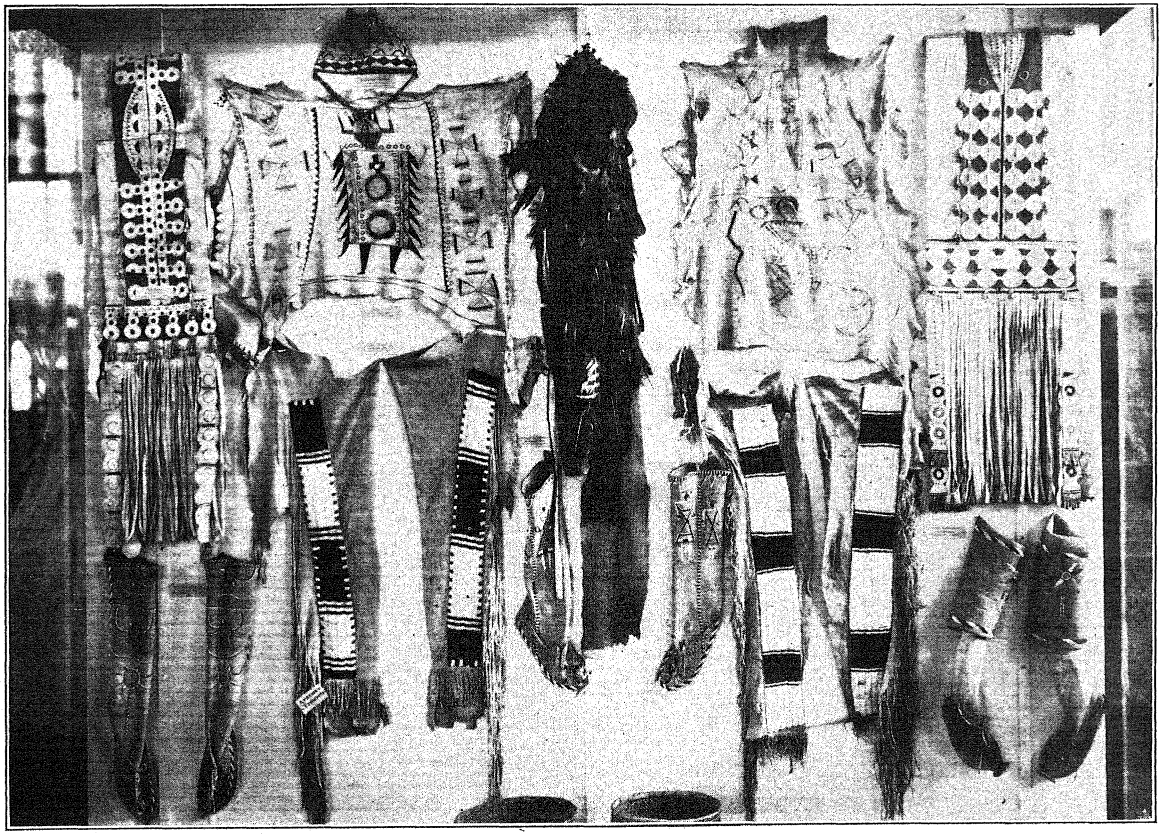
SALISH INDIAN BELTS, WASHINGTON

CENTRAL CALIFORNIA COSTUMES AND FEATHER BASKET

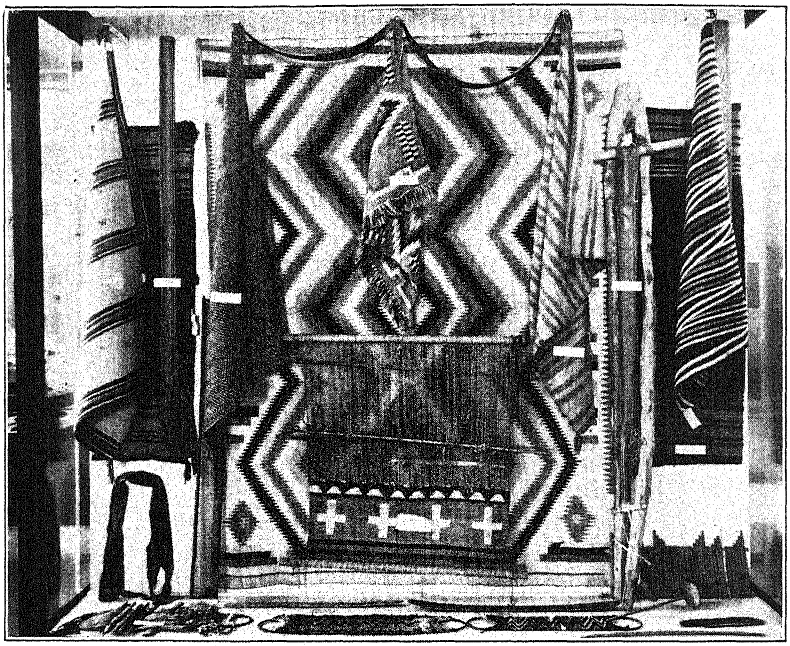
WHITE MOUNTAIN APACHE FAMILY, ARIZONA



HOPI WEDDING BLANKETS AND CEREMONIAL KILTS AND SASHES



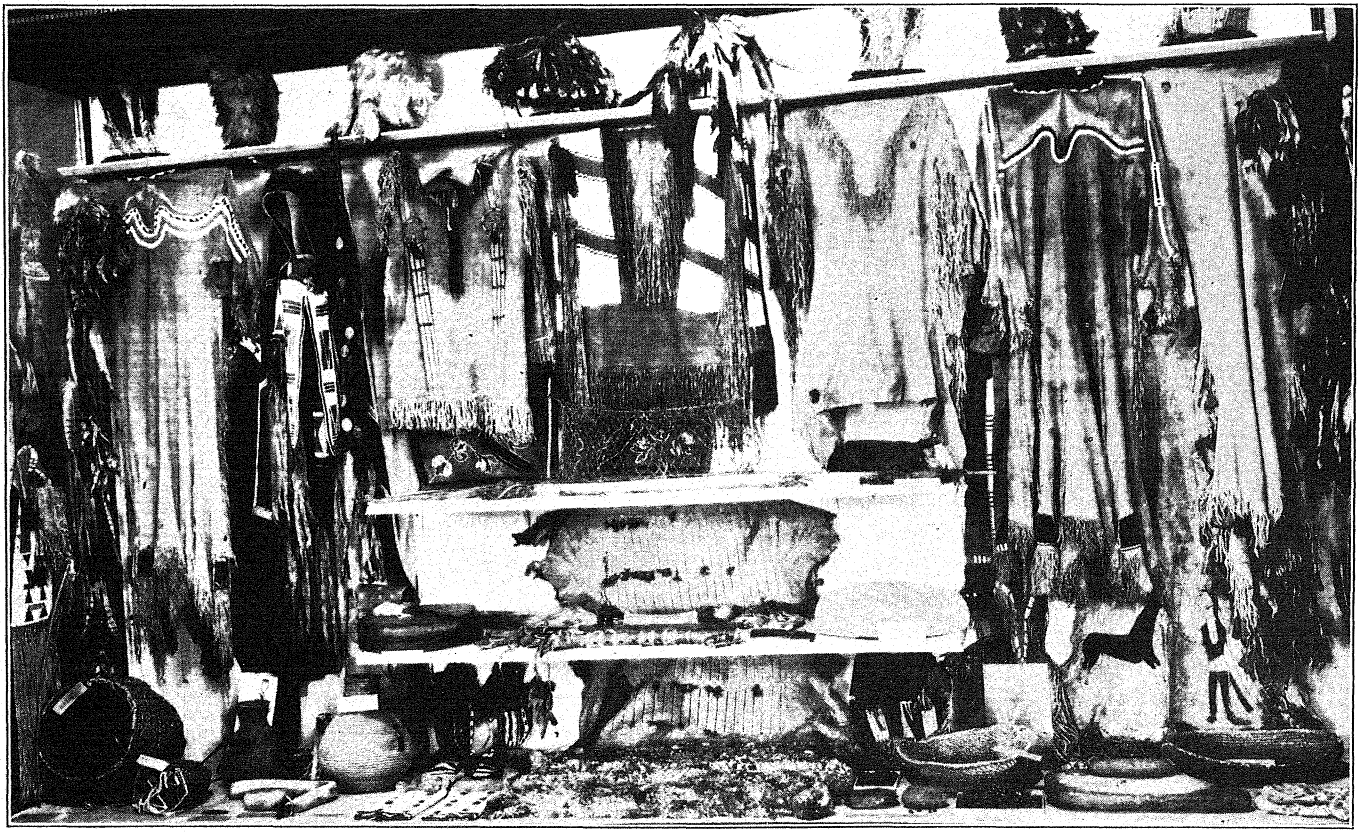
APACHE INDIAN COSTUMES, ARIZONA



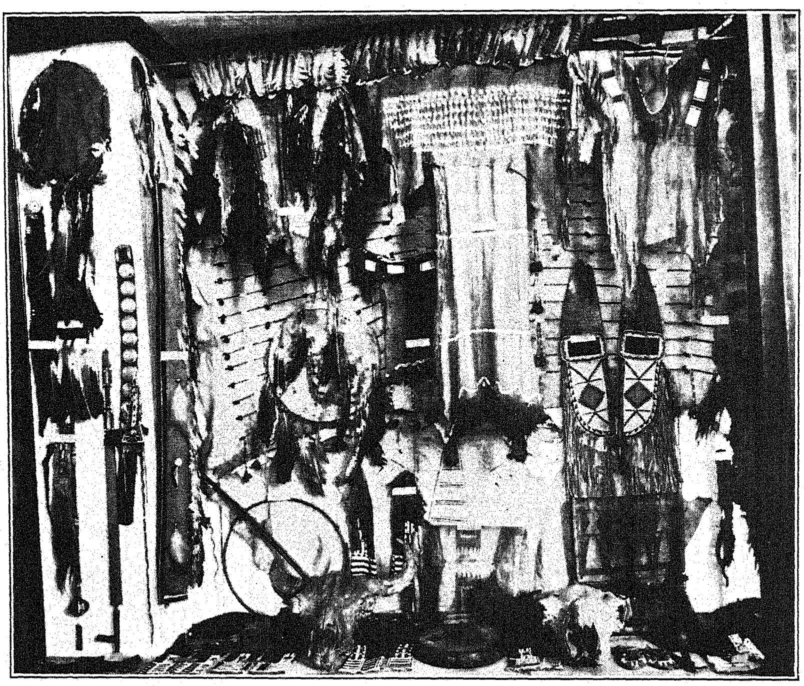
NAVAHO WEAVINGS AND LOOM

NAVAHO SILVERSMITH AND WEAVER AT WORK

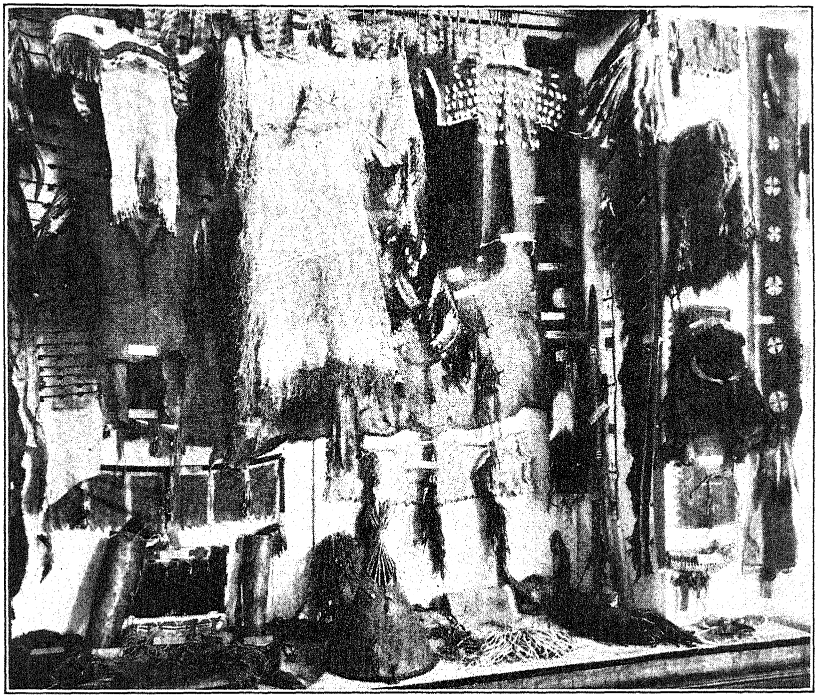
SIOUX WARRIOR IN FULL COSTUME, EFFIGY OF KICKING BEAR



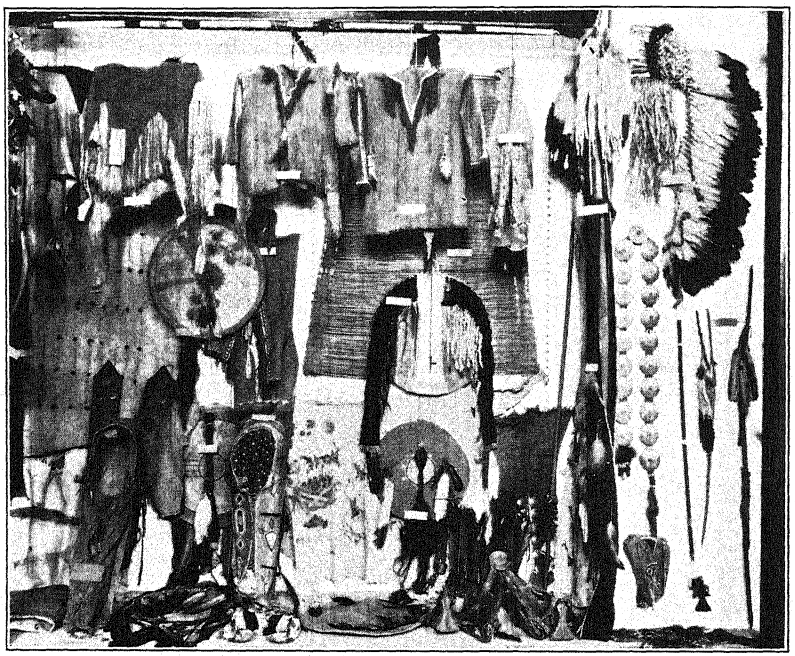
COSTUMES AND ARTS OF THE UTES AND OTHER SHOSHONEANS



CHEYENNE INDIAN COSTUMES



ARAPAHO INDIAN COSTUMES



KIOWA COSTUMES AND ARTS

husks, and unmarried girls among the Hopi continued this practice until recently. Married women wear the hair plaited in two braids. Banged forelocks are general among the several pueblos for both men and women, and men tie their hair in braids with intertwining of fur, yarn, or flannel as among the Plains tribes.

The various pueblos of the Hopi Indians are situated in the semi-arid region of northern Arizona. They mark the most northerly and westerly of the tribes occupying the loom area. The isolated habitat of the Hopi made possible the preservation of the ancient pueblo costumes, as well as customs and traditions, long after the culture of more favorably situated tribes had succumbed to the influence of civilization. In recent times, however, the Hopi have discarded most of their traditional costumes in figured and embroidered wool blankets and robes, and have adopted the cotton cloth and modern costume of the white man.

There are exhibited early examples of embroidery in colored yarns on wool and native cotton fabrics woven with simple hand looms; also plainly woven and subsequently embroidered bride's blankets; figured sashes and kilts used as men's ceremonial costumes; a woman's wool blanket dress, colored blue and with embroidered borders; a child's dress blanket, and a blanket tassel. (Pl. 16.)

Plaiting with the fingers, as well as the simplest loom work, is done by persons sitting or stooping. The feet are not used, either in decussating the warp or in throwing the shuttle. A simple harness of wood is provided, or one is made by seizing each alternate warp thread and attaching it to a rod. The Zuñi woman weaver of New Mexico uses a heddle of reeds pierced in the middle. The attachment of the warp to her belt and to a stick resting against the soles of her feet is an ingenious provision for the tension. The shuttle is a short stick and the batten is a wooden sword. Patterns in belts are wrought by a process of darning the alternate sheds.

The Pima-speaking tribes live on the Gila and Salt Rivers. South of the Pima live a closely related group, the Papago, whose territory extends well into northern Mexico. These tribes are less given to the peaceful arts than are the Navaho and may be designated as gatherers so far as pertains to their food habits.

The Yuma or Maricopa, Mohave, and other southwestern tribes are nearly identical in culture and speech. This does not apply to another immigrant group, the Utes, who occupy the territory north of the San Juan River. Their linguistic relationship with the Hopi is also shared with another Shoshonean tribe, the Chemehuevi.

The Jicarilla and Mescalero Apache and the Utes dress much as do the western Plains tribes, and their habits generally are those of the bison hunters of the Plains. The Apache Indians living in Arizona and New Mexico have been in contact with white people

for 350 years, but, unlike the Navaho herdsmen, have adopted with the greatest reluctance any of the ways of civilization. They dress in skins, but the gradual destruction of game has compelled them to use materials obtained from the whites in their clothing, but they follow the ancient methods and patterns as much as possible. The art of the Apache is best represented in leatherwork and basketry. A number of examples of the former are shown in the exhibit (pl. 17) consisting of saddle pouches, leggings, and an interesting painted mantle supposed to possess the quality of rendering its wearer invisible.

The Mescalero and other Apache women wore a two-piece dress—an upper garment and a skirt. The upper garment was provided with an opening for the head. Two flat pieces of skin dropped from the neck in front and behind, very much like the woven poncho. The skirt extended from the waist to the knees and was of fringed buckskin. The dress of the men was more scanty and consisted of a skin shirt, a breechcloth, legging moccasins, and a robe for winter use.

The Pima, Maricopa, and Papago Indians, living on the lower Gila and Salt Rivers in southwestern Arizona, have coalesced to a great extent and are now practically uniform in culture. These tribes formerly made blankets from native cotton which they raised in their fields, but their modern representatives wear a simple breechcloth in summer, to which is added in winter a skin shirt and usually a rabbit-skin robe. Rawhide sandals are usually worn by the Pima, although a softer variety made from buckskin is sometimes used.

The Mohave men wear only a cincture of the interior bark of the willow or the cottonwood tree, and the women wear a skirt of the same material reaching to the knees. For the purpose of comfort, as well as for ceremony, they paint their bodies with different colored clays, a custom widely dispersed over the warmer parts of the continent in ancient times. A scarf or handkerchief is worn about the head to confine the hair. White cotton trousers like those of the Pueblo open on the outer sides. They have borrowed this peculiarity from the Spanish, while from the Navaho they have borrowed the use of a type of woven blanket.

The Papago Indians, like the Mohave, wear a scanty costume and that modified after the European pattern. The men formerly wrapped skins about their loins, and women were clad in fringed petticoats of shredded bark and leaves. The Cocopa Indians likewise wore little clothing in an environment characterized by a hot and dry climate and restricted animal life. Simple cord work and weaving for nets and clothing was practiced. Ornaments for head and neck consisted of shell, feathers, and other objects.

The non-Pueblo Tribes of the Southwest have a less specialized culture than that of the Pueblo Tribes. An exception might be cited in the case of the Navaho, who cultivate the soil and are noted for the excellence of their weaving and for their success in herding of sheep. Their basketry is not remarkable and is inferior to that of some of the other non-Pueblo Tribes. The Navaho loom is crude, but the work is much sought after, and strong fabrics are produced. In the exhibit (pl. 18) examples of the loom and tools and blankets, saddles, rugs, cinches, belts, and garters are shown.

The Navaho prepare the wool of the sheep entirely by hand. Their spindles are of the simplest kind and are so designed that the lowest end must rest on the ground. The beams for the warp, the rude harness for making the sheds, the shuttle made from a long rod without notches at the ends, and the batten sword removed after each weft thread is laid all place this loom among the simplest ever devised. (Pl. 19.)

The costume of the Navaho consists of a pretty woven blanket dress, belt, and of legging moccasins. Men wore war hats like those of the Zuñi; otherwise the man's costume was like that of the Plains Indian. It consisted of a skin shirt, leggings, and moccasins. Belts of silver plaques and much other jewelry of shell beads and silver is worn.

The older specimens of the fine weaving of the Navaho are far superior in color and design to the modern samples of weaving. The introduction of bright aniline dyes and made-to-order patterns has brought about the virtual extinction of the old art. The Navaho weaving industry has now reached an economic phase and is one of the chief supports of the tribe.

Practically all of the Navaho blankets are made by the women, who must also care for the sheep and shear them in season, and even then the woman's share of the work has only just begun, for she must later carry the wool to camp. Fortunately the summer camp or hogan—in reality nothing more than a rough shelter—is conveniently located.

After the wool has been taken from the sheep, it is usually washed and then hung over near-by grease-wood bushes to dry. There are some black sheep in the herds of the Navaho, and to the black and white colors of the natural wool and the few native dyes employed there have been added the store aniline dyes. The wool of the black-colored fleece has a tinge of red, so that it must be dyed to produce a jet-black color. Twigs or leaves of sumac are boiled for several hours; to the resulting liquid is added burnt ocher and piñon gum, and the mixture is continually heated until a charred powder remains, giving a native black dye for coloring textiles and tanned hides. Old blue from Spanish indigo gave the shade of blue seen in

the old bayeta cloth. A yellow-green dye was formerly made from the flowering tops of the rabbit weed by boiling it for several hours and adding to it a mordant in the form of alumn. This gives a number of different shades from a canary yellow to an olive green. The old Spanish bayeta "baize" yarns have a deep-red, old-rose, and various other colors toward the violet end of the spectrum. These colors are in part due to aging as far as concerns the original bayeta colors characterizing the cloth of which the Spanish army uniforms were fashioned and from which bayeta yarn is raveled.

The weaving in soft materials is done on a rude loom, the warp being attached to a primitive sort of frame, and the weft thrown across the warp by means of a shuttle, which is merely a stick on which the weft is wrapped. The ornamental motives are the same as those found on Navaho basketry and pottery, being derived for the most part from the native religious symbolism. The patterns of Navaho rugs and blankets of recent years have departed far from the older dignity and simplicity. The decline in weaving which set in with the introduction of European and American cloth has again given way to a revived interest in native Navaho weaves, although the weaving of the Hopi has narrowed down to the making of garments needed in the tribal ceremonies. Early examples of Navaho weaving showed broad stripes (pl. 18) and geometrical figures either singly or in combination with other figures followed. Common designs are diamonds, squares, and triangles. The practice of introducing designs extending only a short distance across the blanket may have originated with the Navaho, as the Hopi weave only continuous stripes and add embroidered designs later. The common supposition is that Navaho zigzag, triangular, rectangular, and other geometrical designs were incorporated into their blanket weaving after the fashion of their basketry designs. The woof strand of a desired color is carried only as far as that color is needed to complete the design, and is then dropped.

In weaving, the warp threads are separated into two divisions, called sheds or sets of warp strands. Alternate threads are caught up in yarn loops attached to two small sticks. The two sets of threads are separated by pushing down a rod between them and are crossed by pulling up on the stick to which the loops are attached.

Dress of the Plains tribes.—The so-called Plains Indians lived for the most part in the area covered by the open grasslands of the western plains west of the Mississippi and east of the Rocky Mountains. Their hunting ranges were the lands grazed by the bison, or American buffalo, and the most typical of the Plains tribes occupied the regions where the bison was most readily hunted. As the bison moved from one grazing area to another the Indian of the Plains followed. This nomadic hunter's life was not conducive to the prac-

tice of the sedentary arts, and the Plains Indians, therefore, had no agriculture, made no pottery, and wove no cloth.

The numerically strongest linguistic stock among the Plains tribes was the Sioux; other stocks were the Shoshoni, Kiowa, Caddo, and Algonquian. Some of the more typical northern Plains tribes are the Assiniboin, Blackfoot, Crow, Gros Ventre, and Teton-Sioux, while the southern tribes included the Arapaho, Cheyenne, Comanche, and Kiowa. After the introduction of the horse among the Plains tribes, they became more mobile and nomadic than formerly, when the dog was their only burden carrier. Irruptions of one group upon the hunting lands of another became more frequent, and hostile encounters became almost continuous. The more aggressive hunters as the Blackfoot, Kiowa, and Comanche were generally feared by the less aggressive tribes, and even by the sedentary agricultural Pueblo Tribes who were often raided by the Kiowa and the Comanche.

Along the eastern fringe of the Plains lived the Wichita, Pawnee, Omaha, Osage, Iowa, Arikara, Oto, Mandan, and Hidatsa. These tribes resembled the typical Plains tribes in their mode of dress, but differed from them in that they lived in houses of earth, mat, or grass construction, made pottery, cultivated maize, and wove baskets.

Another group of tribes resembling the tribes of the Plains lived west of the Rocky Mountains and occupied the plateau region now forming the States of Idaho, western Montana, Utah, and portions of adjoining States. These tribes, the northern Shoshoni, Nez Percé, Bannock, and Ute, resembled the Plains tribes in their mode of dress, but differed from them in their social organization and other culture traits.

In Plains costumes all dresses have the same generalized outline of open pendent sleeves and a scored bottom showing four scallops or crests. As the dress is made of two deerskins, the varying outline or tribal pattern is derived from the sewing of the garment. Trimming of the edges varies from tribe to tribe. The free edges were generally fringed, and quill embroidery, beadwork, painting, scalp locks, tails of animals, feathers, claws, hoofs, shells, and other objects were applied as ornaments.

In a general way skin clothing was used by all of the Plains tribes instead of basketry or woven cloth, although some fashioned woven robes of rabbit skins. A good example of true weaving on the part of Plains Indians may be seen in the sacred bundles of the Osage, where buffalo hair is employed. The Omaha are supposed to have formerly woven belts, and the Nez Percé still plait bags of bark with imbricated overlay of grass in geometric patterns. These tribes are marginal and may have acquired their weaving knowledge along with other borrowed traits from their non-Plains neighbors.

Women of the Plains tribes wore a sleeveless dress cut and sewed as a 1-piece garment. Formerly the Cheyenne, Pawnee, and Osage women wore a 2-piece dress consisting of a skirt and a cape, which is more typical of the woodlands tribes of the Eastern States.

Tribal leaders and those enjoying social distinction within their group not only bedecked themselves with a highly ornamental feather headdress with its long streamer of eagle feathers, but were entitled to wear a so-called war shirt. This garment, also known as the scalp shirt, does not belong to the regular costume, but when stripped of its decorative ornaments and accessories resembles the typical shirt of tanned deerskin. The wearing of the decorated war shirt was peculiar to the northern Assiniboin, Crow, Dakota, and Blackfoot, but has been adopted by the Kiowa, Osage, Arapaho, and other southern Plains tribes. The northern Shoshoni, Cree, Dene, and other northern tribes of the Plains had long ago taken over the use of shirts of tanned leather.

In the Museum figure of a Sioux Indian warrior (pl. 20) there is shown the use of a somewhat modified form of a war shirt trimmed with beadwork, cut fringe, and scalp trophies. Other objects of personal adornment and of wearing apparel are a plume of eagle feathers, necklace of bear's claws, cincture of flannel, trousers of deerskin dyed green, and moccasins ornamented with porcupine quills. In his right hand the figure carries the old stone war club of the Sioux; the face is that of Kicking Bear, a Sioux medicine man who was prominent with Sitting Bull in the ghost dance craze among the Sioux in 1890. A cast was made when he visited the Museum in 1902, at which time the costume was also secured from him. The decoration painted in kaolin on his hair is a cross within a circle and is a heraldic device signifying an act of prowess in which he saved a friend under the fire of the enemy.

The Sioux Indians belong to the Siouan family, formerly having a wide distribution west of the Mississippi Valley as far southward as the borders of Louisiana. Detached tribes were also living at the time of the discovery in the mountain regions of Virginia and North Carolina.

The Comanche Indians formerly ranged the southern Plains principally in the region now the State of Texas, but what is left of the tribe now lives in Oklahoma. They belong to the Shoshonean stock, but their arts and industries are those of the tribes of the Plains, though somewhat ruder, and these arts have little resemblance to those of their own kin, the Utes. The specimens exhibited in the Museum are cradles, lances, shields, saddle, beadwork, and costume.

The Utes and other Shoshoneans ranged from Utah to Montana and Washington. This case (pl. 21) contains costumes of an early day collected by Maj. J. W. Powell, Emile Granier, and others.

Feather head dresses, basketry, rabbit-skin robes, and various ceremonial objects are illustrative of the stage which had been reached in their arts and industries. In general, the culture of these tribes was low and the lack of color as contrasted with the Plains tribes noticeable.

In the plateau area, the common form of robes for winter use were of antelope, elk, and mountain-sheep pelts, while in summer tanned skins without the hair were worn. The piecing together of skins of the smaller animals was resorted to, also the weaving of a blanket from strips of rabbit skin was practiced. The use of this latter form of robe extended from Canada to the Southwest but was not taken up by the central Plains tribes. The buffalo robe of the Plains tribes was fashioned from the entire skin including the tail, and the robe was so worn as to bring the tail section on the right hand side.

The plateau area is generally understood as including the upland portions of Utah, Nevada, and the States on the north, including British Columbia. This region was more or less arid and inhospitable, and therefore was never the home of a large population. Wild grasses, seeds, roots, and fish played an important rôle in native culture. The weaving of baskets reached a high state of development and the weaving of textiles from bark fibers was practiced to some extent. Many of the tribes of this area borrowed much from the nomadic Plains tribes, and the Nez Percé, Bannock, and others are garbed very much like their neighbors of the Plains; while the tribes of the middle and upper Columbia and of the interior of British Columbia accepted many of the culture traits of the coast Salish.

The Nez Percé Indians belong to the Shahaptian stock, living on the middle portions of the Snake River Valley in the States of Washington and Idaho; they dress in buckskin shirts and robes of buffalo hide. So far as leggings, moccasins, shirt dress for women, and other accessories of wearing apparel are concerned, their dress is very much like that of the northern Plains tribes neighboring on their right. There is one peculiarity of dress pertaining to the decorative designs on their war shirt. Somewhat like the saddlebag of the Apache, the war shirt of the Nez Percé is pierced with innumerable small circular holes, which are never more than a third of an inch in diameter, but cover the entire shirt. The smoked, salmon-colored, tanned deerskin with this unique ornamental motive worked out in symmetrical fashion is beautiful indeed. (Cat. No. 22851, U. S. N. M.)

A warrior's costume from the Piegan Indians of Montana, collected by R. H. Pratt (Cat. No. 153589, U. S. N. M.), carries out the same decorative motive as in the Nez Percé shirt, but in the form of dots painted black, a form of ornamentation which gives the same

general mottled effect. The shirt is of deerskin, ornamented with short, cut fringes, bands of beadwork, fringes of ermine skin, red feathers, and dyed horsehair. The leggings accompanying this shirt are of deerskin, adorned with a cut fringe, band of beadwork, ermine skins, horsehair, and red feathers.

If we turn to the southern Plains we find several typical tribes of the area, one of which is the Cheyenne. The Cheyenne are southern Algonquians who live in Oklahoma, and their arts and modes of life resemble those of their neighbors of the Plains, especially the Arapaho, to whom they are related by speech. The specimens shown are costumes, robes, painted rawhide cases, lances, shields, and cradle, all ornamented with paint, feathers, beads, and elk teeth. A buffalo skull from a sun-dance altar is placed on the floor of the case. (Pl. 22.) A number of objects of dress within the exhibit illustrate the variety of decorative work in quills of the porcupine. Quill work preceded largely work in beads, as quills were easily dyed and enabled the artist to combine colors. They were applied in many different stitches to moccasins, shirts, leggings, belts, pouches, knife sheaths, cradles, birch-bark trays, boxes, fringes, necklaces, etc., of which some examples are shown in this and other cases.

The Arapaho live in Oklahoma with their kinsmen, the Cheyennes, although originally they lived on the northern boundary of the United States. The specimens in the case illustrate clearly how much their arts must have changed in their transfer to the lower latitude, since at present their material culture is that of the Plains. The exhibit (pl. 23) consists of costume, robes, cradles, painted-rawhide cases, lances, and ceremonial objects.

The Kiowa Indians also live in Oklahoma. Their language is distinct, but their arts, at the time when they were studied, were, in the main, uniform with those of the Plains tribes, though in symbolism and heraldic art the Kiowa have a system of their own. The exhibit (pl. 24) contains a costume of deerskin, colored by rubbing with blue mineral paints, headdresses, lances, shields, painted rawhide cases, beadwork, cradle board, flute, and shinny stick.

A complete costume for a Kiowa man was collected by James Mooney in 1893. (Cat. No. 152841, U. S. N. M.) It includes nine pieces—hair clasp, hair rolls, earrings, necklace, shirt, breastplate, sash, breechclout, leggings, moccasins, hair wheel, and bead strings. The shirt is of buckskin, painted green and ornamented with cut fringes in blue and beadwork; shoulder ornaments of oriole skin and feathers; leggings of buckskin trimmed with cut fringe, red flannel, and beadwork; beaded moccasins with fringed flaps; and beads of several colors.

Another man's suit from the Kiowa consists of a shirt of buckskin with sleeves and a triangular breast piece with cut fringes, leggings

of buckskin, painted green, and heavily bordered with cut fringes and lines of beadwork. Near the bottom is a coil and eagle design in beadwork. The moccasins of buckskin, painted green, have stiff soles and vamp ornamented with cut fringe and beadwork; trailers on the heels are of cut fringes. (Cat. No. 169083, U. S. N. M.) The moccasins of the Sioux are made of buffalo hide and deerskin, with rawhide soles and uppers in one piece, covered with beadwork in triangular designs.

On women's dresses from the Kiowa the shirt dress is sleeveless, the yoke is beaded with cowrie shells from the Indian Ocean procured in trade. Formerly, when elk were abundant, the milk teeth occupied the place of the shells. Leggings and moccasins are in one and are ornamented with red flannel, beadwork, and silver-plated buttons. (Cat. No. 152851, U. S. N. M.)

Most of the Plains Indians wore long leggings tied to the belt. Women's leggings were short, extending from the ankle to the knee and supported by garters.

There was no special covering for the head. Northern Plains tribes wore fur caps at times. In the South and West the head was bare, but the eyes were protected by shields of rawhide. Both sexes went bareheaded, but on occasion pulled up the buffalo robe into the form of a hood. The hands were not covered.

The Sioux may be regarded as a type of the nomadic hunting tribes of the Western Plains. The Plains tribes overran an enormous territory including portions of Manitoba, the Dakotas, Nebraska, Kansas, Texas, and neighboring regions. The principal groups as the Sioux, Nez Percé, Sauk and Fox, Cheyenne, Arapaho, Kiowa, and Comanche, all have assumed, or are at the point of assuming, the habits of civilization.

The specimens shown in Plates 25, 26 are from several tribes of the Siouan stock. In most instances it is not possible to definitely assign Siouan specimens by tribes, as the customs and arts became exceedingly mingled before the practical extinction of the tribal government in the latter part of the nineteenth century. The exhibit, however, gives an impression of the Plains culture in comparison, for instance, with that of the Northwest coast or pueblo region.

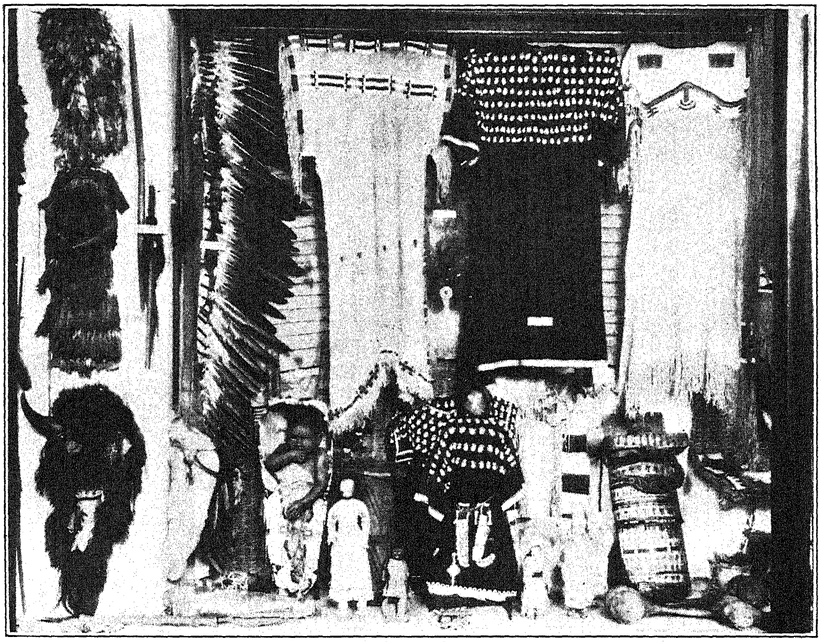
In Plate 27 is to be seen a Sioux Indian woman dressed in beaded buckskin frock with cut fringes, earrings of dentalium shells, and leggings and beaded moccasins. In her left hand she carries a spoon carved from cow's horn.

The costume and cradle belonged to the Dakotas who came early in contact with the French explorers. Their clothing, their tents, and their utensils were made largely of skin. (Pl. 28.) Formerly quills of birds and of porcupines were used in decoration, but beads have taken their place.

Indian tribes of the Plains have a highly developed conventionalized art which they express in worked designs applied to clothing and other objects. Paints are also applied principally to bags, cases, and to the so-called parfleches of rawhide. Decorative designs in beads, quills, and paints are uniformly geometric in composition, although military exploits, time counts, and other historical events are portrayed on garments and other objects of skin in realistic patterns. Glass beads were introduced at an early date by French, English, and traders of other nationalities and have tended to supplant the sewed decorative embroidery work in dyed and undyed quills. Quills were formerly applied to large areas on the surface of skins in round, square, and linear geometrical designs. One of the best examples of early embroidery work in porcupine quills may be seen in the exhibit of skin garments collected by George Catlin prior to 1838 from various unidentified tribes. This exhibit is marred somewhat by the damaged condition of the costumes, as the Catlin collection has passed through several fires. Enough remains, however, of the designs to demonstrate the excellence of the work (pl. 29). All types of geometric design in sewed or embroidered bead and quill work occur upon the garments, bags, and especially moccasins and leggings of any particular tribe. Tribal design types may, however, be identified by the frequency with which they are found. The general tendency appears to be a borrowing from pictographic designs of the eastern woodlands tribes, as the Chippewa, on the part of the Plains tribes occupying adjoining areas, and from the geometric basketry designs of the Southwestern tribes on the part of the Ute and other plains-like tribes of the plateau area.

Tribes of the weaving area of Mexico, Central and South America.—The Indians of Mexico have always been skillful weavers, and it is known that in this region the art of weaving was quite ancient. The Mexicans were proficient dyers and displayed considerable taste and invention in the ornamentation of textiles. The loom is simple and appears to be an aboriginal invention.

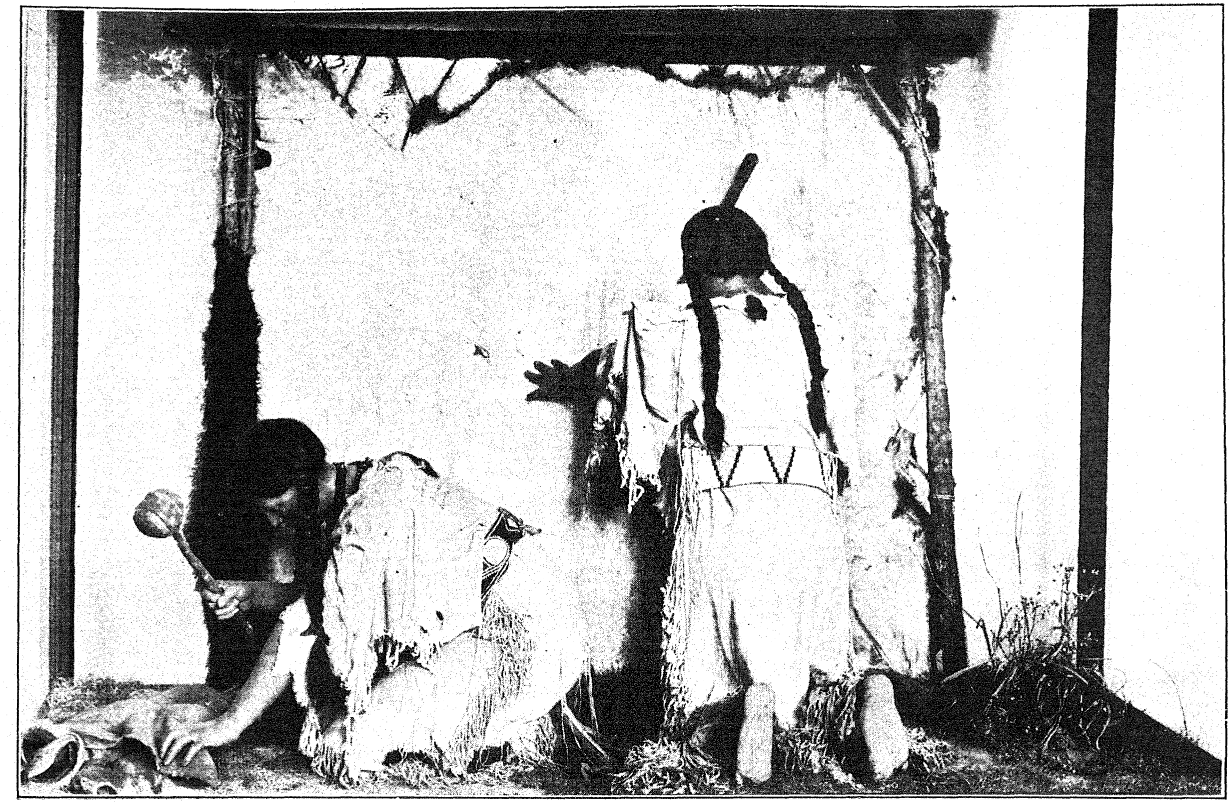
The Maya-Quiche Indians of Guatemala and Yucatan, also of Chiapas and a small portion of western Honduras, wove delicate fabrics. Other Mexican Indian tribes represented in the Museum collections of Mexican textiles are the Cora, Tarahumara, Huichol, Aztec, and Chiapas. The serape blanket from Saltillo, Mexico, is the outstanding textile garment from Mexico. There are several serapes exhibited that are beautifully woven in the subdued colors possible only through aging and the use of native dyes. The art of the Mexican serape weaver surpasses that of the Navaho blanket weaver at her best. Two of the excellent specimens of Mexican serapes are to be seen in Plate 30, which were made in Saltillo, Mexico, before the use of modern aniline dyes prevailed. One (Cat.



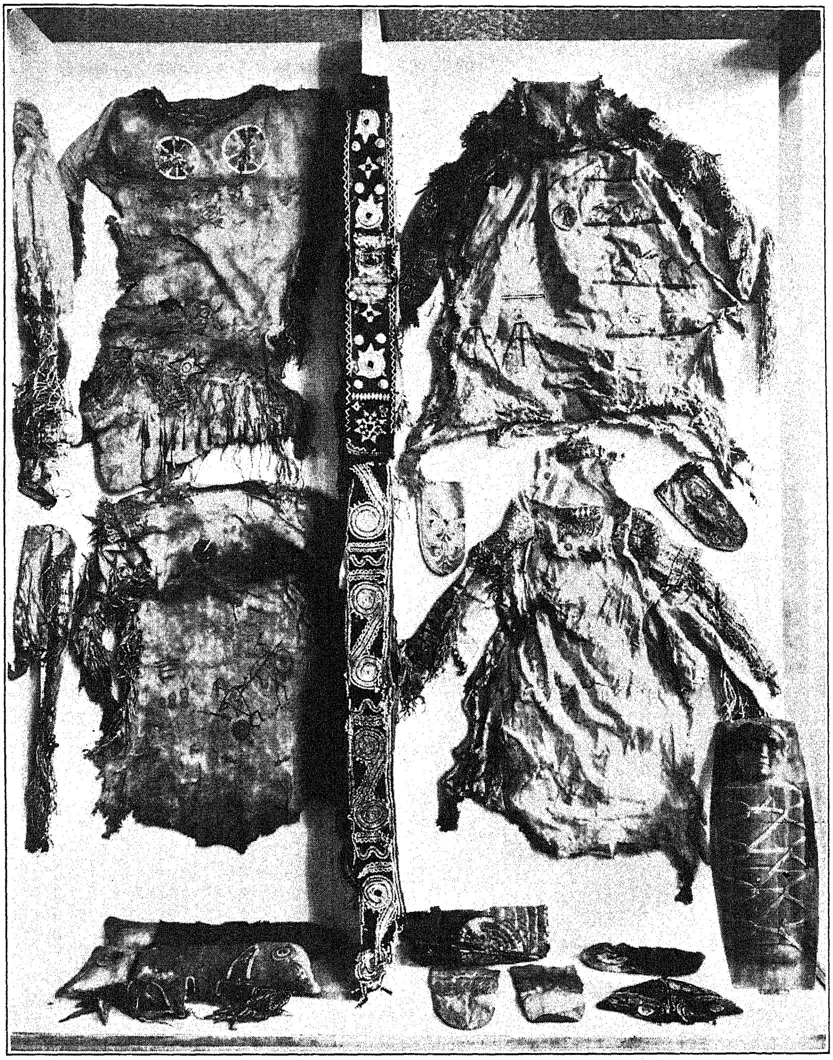
SIOUX INDIAN DRESSES, DOLLS, CRADLES, ETC.

SIOUX INDIAN EXHIBIT

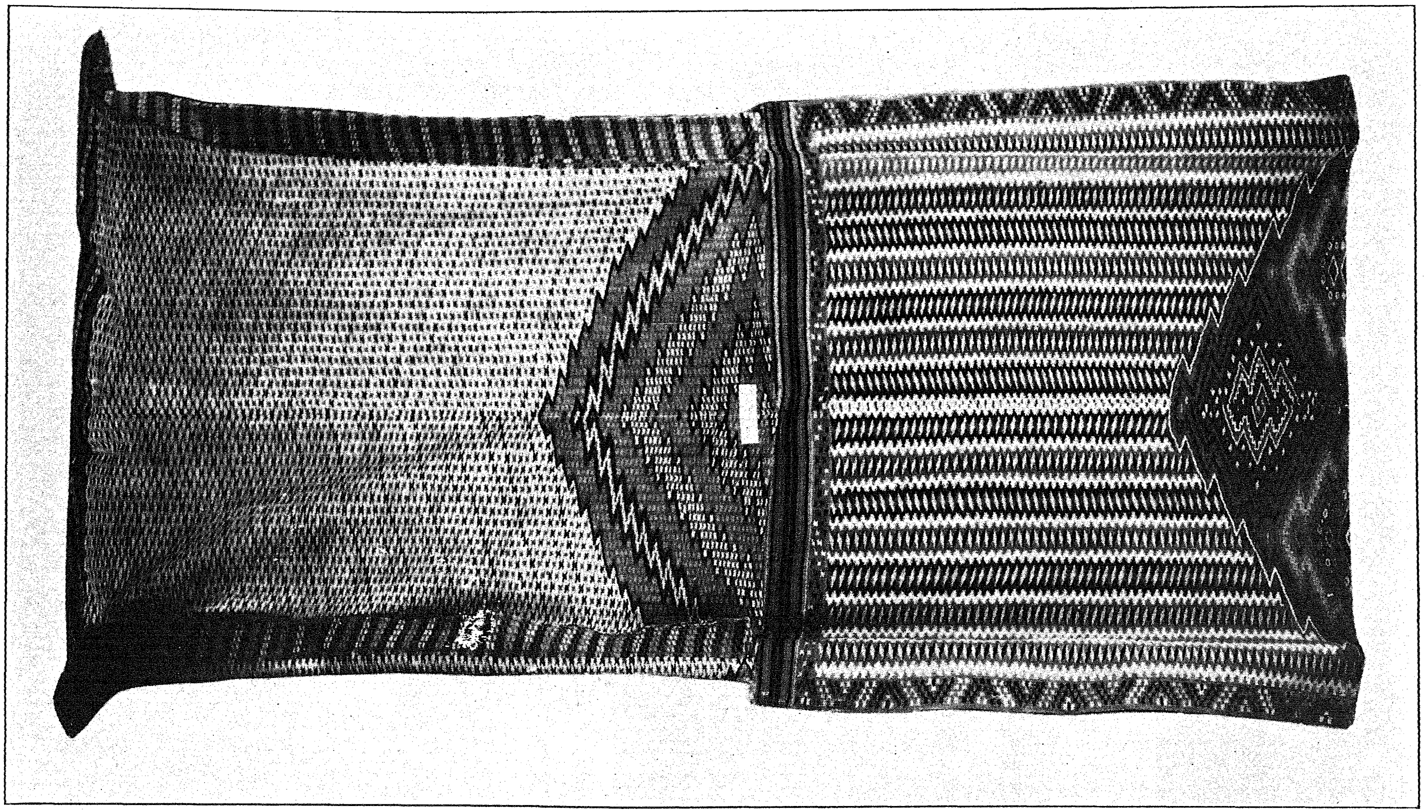
SIOUX INDIAN WOMAN WITH CRADLE



INDIAN WOMEN DRESSING BUFFALO HIDES



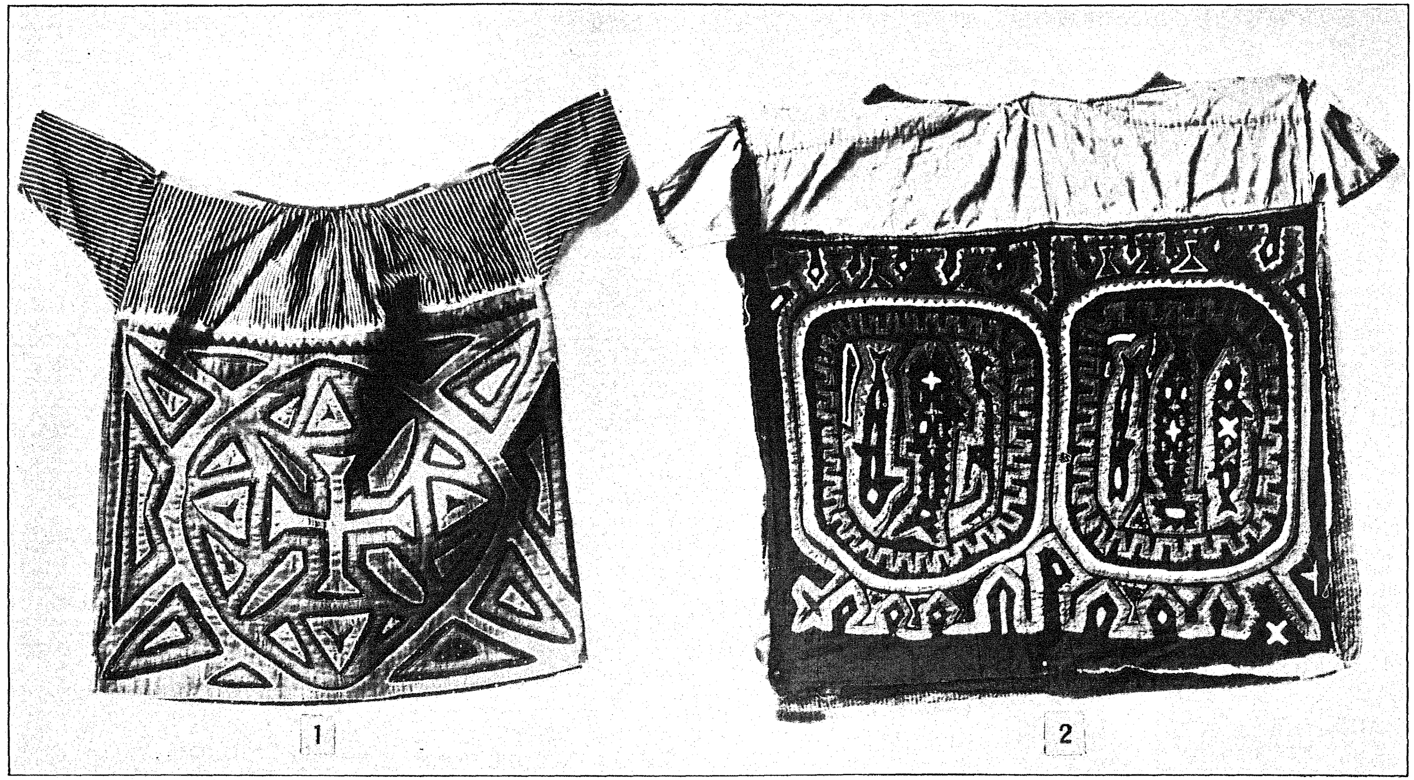
RELICS OF EARLY PLAINS INDIAN COSTUMES, GEORGE CATLIN COLLECTION



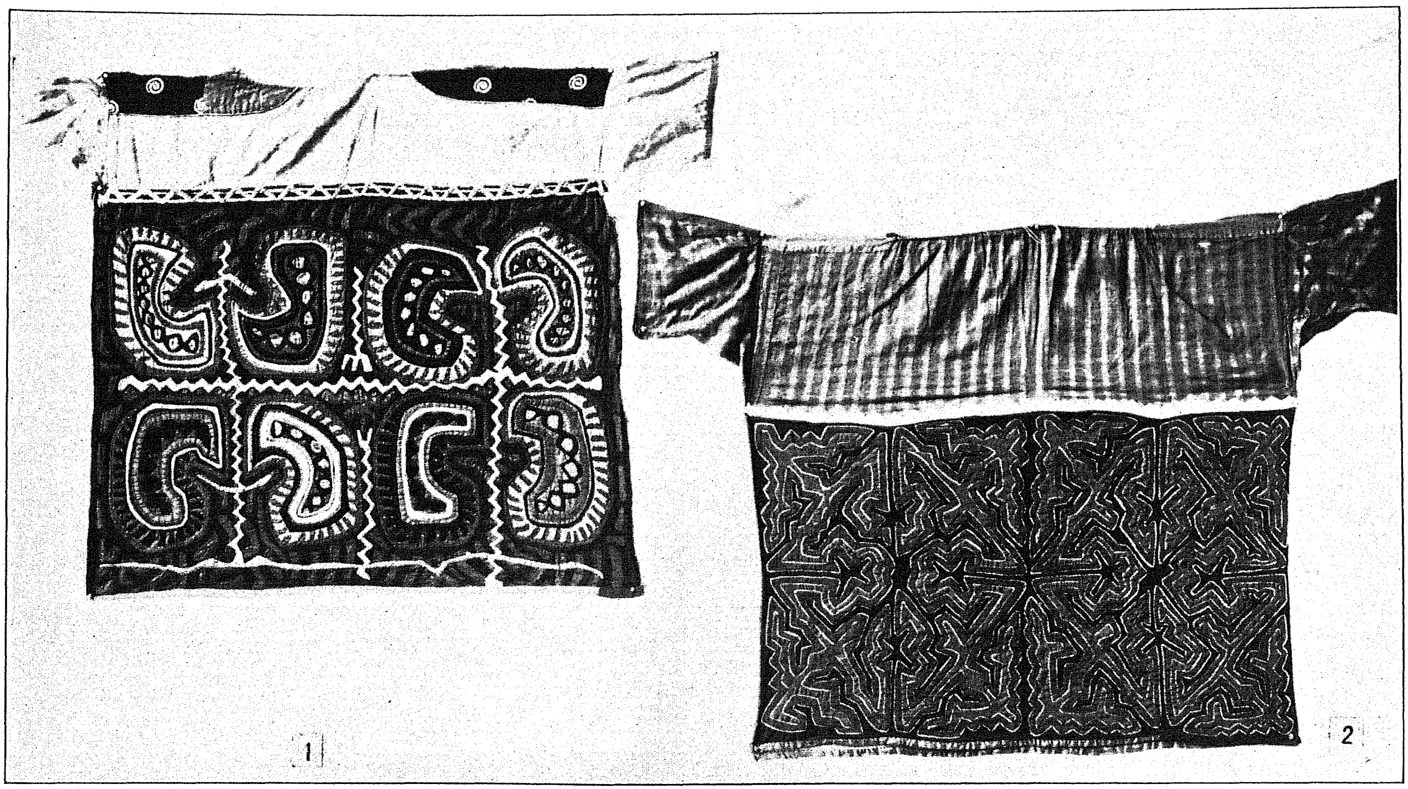
SERAPES WOVEN IN SALTILLO, MEXICO

1, 2, 3, CHOCO INDIAN COSTUMES, PANAMA

1. CUNA GIRL IN FULL COSTUME. 2. TULE GIRLS, SAN BLAS, PANAMA

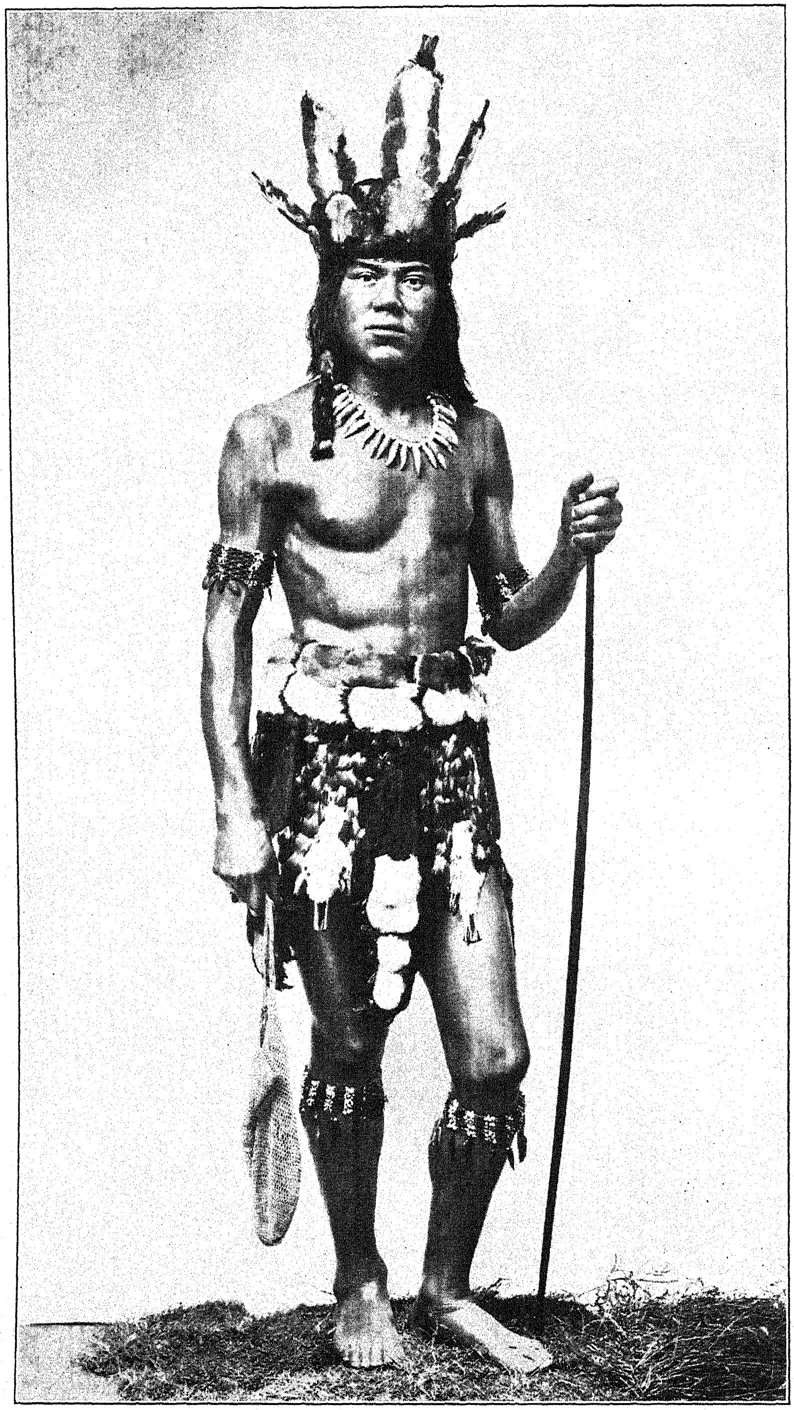


1, 2. TULE INDIAN WOMAN'S JACKET, APPLIQUÉ WORK, PANAMA



1, 2. TULE INDIAN WOMAN'S JACKET IN APPLIQUÉ, PANAMA

ARAUCANIAN WEAVER, CHILE



JIVARO INDIAN IN FEATHER COSTUME, SOUTH AMERICA

No. 326875, U. S. N. M.) came as a gift of Mrs. H. M. Packard; the other (Cat. No. 339886, U. S. N. M.) was presented by Mr. Darwin Weaver. The Saltillo serape is the best example of the blanket weaver's art, although weaves and textiles from tribes occupying other parts of the Mexican tableland are also highly artistic. Some of the outstanding examples of Mexican Indian textiles were collected for the Museum by Walter Hough, Edward Palmer, E. W. Nelson, A. Hrdlička, and W. H. Holmes.

An interesting collection of middle American textiles and articles of dress was made by W. H. Gabb, principally among the Talamanca Indians of Costa Rica and Guatemala. It includes masks and dance costumes, woven belts, sashes, embroidered cotton jackets, ceremonial headdresses of feathers and bark, and bark-cloth blankets.

The tribes of Panama are of interest as forming the connecting link between the Mexican, Central American, and South American cultures, being on the whole more closely allied to the latter. The Chocó Indians of southeastern Panama, for example, are related culturally to the adjoining Chocó Tribes of the Cauca River Valley, of northern Colombia. Ear pendants carried by the Colombian Chocó are long wooden tubular plugs, resembling those in the Museum collection from the Panaman Chocó. A silver disk of thin rolled silver is mounted over the outer surface of the bulbous end of the plug.

The Chocó woman's dress is ordinarily quite simple like that of the Tule, consisting of a piece of calico cloth several feet long wrapped around the hips, forming a skirt extending a little below the knees. (Pl. 31.) Little girls are given one of these skirts at puberty; at the same time the little boy is given his first breechcloth.

Pieces of bark cloth were formerly much utilized by the Panaman Indians as clothing and for various other purposes, such as matting, bedding, breechclouts, and women's short skirts. Bark cloth has decorated surfaces consisting of parallel, diagonal lines and of other geometrical figures made with a black dye. All of the Panaman Indian Tribes understand the use of the loom and of the spindle. The Talamanca of Costa Rica, the Cuna and Tule of Panama all employ similar devices and weaving implements. One of the examples of loom work on which the Darien Indian lavishes his best efforts in figured design is the woven headband, worn on gala occasions. It is woven on a simple weaving frame.

The Cuna Indians of the Panaman interior were formerly supposed to have a system of pictographic writing expressed in appliqué work. The designs were copied by the Tule (pls. 32, 33), but the ideographic significance of the characters and animal figures remained unknown to them. The use of an appliqué-embroidered woman's garment in the form of a chemise was first brought to view

in the collection presented by Mrs. E. Y. Bell. The designs are highly conventionalized and have several layers of cut and insert appliqué work (pl. 34).

The Mexican tribes are represented in the Museum collections by articles of dress, by sashes, satchels, and serape blankets; the Central American or Mayan Tribes by fabrics in which the old geometric conventional designs of mythological character are preserved. South America furnishes excellent examples of the native art, ancient and modern. The burial places of Peru yield textiles of almost unrivaled artistic excellence. The sleeved shirt in openwork pattern and the sleeveless garment in Gobelin style, ornamented with great numbers of conventionalized bird forms, are typical objects of dress, while the fragment of a crimson mantle is a marvel of textile construction. The body of this mantle is made up of hundreds of separate disks, into which are woven human features, and from the centers hang clusters of minute tassels, the round head of each imitating the human face, while the border is a fringe of tassels of varying size in most tasteful arrangement. Other examples of Peruvian textiles have conventionalized birds and animals as the usual decorative motives.

Although skillful weavers of cotton cloth, the Arawak Indians of the West Indies possessed but scanty clothing. Women wore a short skirt of woven cotton fabric after marriage, but the unmarried girls went naked. In the culturally more advanced districts of Haiti there was a distinction in the type of women's skirts according to the rank of the wearer. A typical garment reached from the waist to the mid-thigh, while the skirts of women of importance extended to the ankle. Among the Lucayans of the Bahamas and the natives of Porto Rico and Cuba the male population went entirely nude. Body painting was resorted to in the absence of clothing. Puberty was celebrated with a feast, after which girls wore a small net filled with leaves and attached to the waist. Both sexes wore ornamental cotton bandages on upper arms, below the knees, and at the ankle. Similar ornaments were worn in Jamaica and are still the fashion among the Indians of southeastern Panama. Ferdinand Columbus, writing of the Carib on the island of Guadeloupe in the Lesser Antilles, refers to the same custom as being practiced there. The presence of these bandages is indicated on wooden zemis (wooden idols) in the National Museum from Santo Domingo. Ferdinand Columbus also states that in one hut on the island of Cuba over 12,000 pounds of cotton was found in the native dwellings, together with a new variety of loom on which it was woven. This loom was possibly of the Central American or Mayan type as contrasted with the regular South American Arawak type.

The aboriginal inhabitants of the west coast of South America south of Peru possessed a crude culture distinct from that of the ancient Peruvians. Loom weaving and other culture traits of the Incas later appeared as far south as the Maule River and are now extensively practiced. The Araucanian Indians formerly occupied the greater part of Chile. (Pl. 35.) To the south were the Choncans and the Ona, who were in possession of a distinct culture centering about the hunting of the guanaco with bola and lasso.

There are exhibited in the national collections from this area woven and embroidered textiles, consisting of figured woven blankets and striped ponchos, woven slings in orange and purple colors, woven headbands striped and decorated with silver beads, figured and fringed woven belts, and other decorated fabrics. The more advanced culture of the region about Lake Titicaca is exemplified by blankets and slings of vicuña wool.

The more primitive jungle culture of the middle Amazon is shown in examples of bark cloth, bright-colored ornaments, and necklaces of seeds or of teeth.

The environment of the upper Amazon varies from the arid western slope of the Andes to the heavily forested region at the eastern foothills. The tribes of the Andean region of Peru and northern Bolivia were characterized by a very advanced culture. Articles in the exhibit from that region demonstrate their skill in weaving. The brilliant feathers and the green-beetle wings were much used for personal adornment by the tribes of the eastern Andes, whose culture becomes more primitive as it leaves the old Inca center about Cuzco. Aprons of beadwork with geometric designs, bracelets and armlets of bark and feathers, and feathered ceremonial gourd rattles indicate the artistic concepts of the Indians of the lower tropical forested region.

A typical example of the Indian tribes inhabiting the forest region of the upper Amazon are the Jivaro Indians of Ecuador. The Jivaro live on the headwaters of the Maranon River. Their costume shows consideration and appreciation of color, which they derive from tropical birds and beetles. The cincture and headdress are made by fastening the feathers of the toucan and blue chatterer to a foundation of bark cloth. The necklace, armlets, and leglets are made of seeds, beetle wings, monkey teeth, and teeth of the puma. The bag carried in the hand is knit from a continuous string. (Pl. 36.) The costume exhibited was collected by W. E. Safford.

Another exhibit from the Jivaro Indians is the collection of J. G. Culbertson. It includes featherwork, beaded aprons, and bandoliers of small disklike black seeds, and dried human heads as ornaments

characteristic of their art. The prepared human head has undergone a process of shrinking, principally through the removal of the bones of the skull and jaw. It has been dried and smoked over the daily fire used for cooking, the hair being wrapped up in leaves to protect it from the smoke. The Jivaro Indians consider such a prepared head a splendid ornament to be worn about the neck as a trophy.

The feathers ornamenting the skirt, headdress, and bandoliers are from a bird with soft orange-red plumage that the natives call "cock-of-the-rock," also from a species of toucan with white breast margined with red and yellow tail coverts. The rest of the bird's plumage is black. Each tuft of yellow or of red feathers, therefore, represents the life of one bird. The armlet and back pendant show the characteristic use of metallic-green beetle's elytra. Monkeys' teeth and the bleached leg bones of birds, together with beads of small disk-shaped black seeds, in part, make up the composition of the bandolier, ear ornaments, and skirt.

The tribes of the Grand Chaco correspond in similarity of location with the Plains Indians of North America and, like them, live a roving life. In the collection of costumes of Indians from Paraguay are parts of costumes ornamented with feathers of tropical birds. There are also shown knitted bags resembling those which are found from the pueblo region to temperate South America.

The introduction of the horse among the tribes of the great South American plains had a tremendous effect upon their culture, as it facilitated the hunting of the guanaco and the rhea, and increased their nomadic habits. From the most typical hunting tribe of Patagonia, the Tehuelche, are exhibited painted robes of horsehide and vicuña skins, spurs, boots, and other articles of dress connected with their horsemanship.

In addition to the outstanding collections of costumes from South American tribes to which mention has been made, reference should be made, among others, to the following: From the temperate regions of South America, a robe of rhea skin, collected by J. B. Hatcher from the Tehuelche Indians of Patagonia; the Hassler collection of netted bags from Paraguay; knitted leggings from Peru, by W. E. Curtis; and gloves of llama wool, by W. E. Safford, who also collected and presented a large number of other articles of dress from the Indians of Peru, Paraguay, Bolivia, Ecuador, and Chile. The large collection of paintings made for W. E. Safford by a Bolivian Indian show to advantage the dress of various tribes in Bolivia, Ecuador, Tierra del Fuego, Peru, and other lands in South America. An exchange collection from the Museum of Buenos Aires includes a cord war shirt from the Chorote Indians of the Chaco in the

Argentine, while the J. N. Ruffin collection includes a war shirt from a Paraguay tribe. In this collection are objects from the Calchaque Indians and others in the Argentine. The P. Figyelmessy collection from British Guiana includes feathered headdresses, while other headdresses from the Jamamadi of Brazil are represented in the J. B. Steere collection. Blankets from the Araucanian Indians of Chile are represented in the D. S. Bullock collection, while a large collection of skin robes, blankets, and ponchos from Bolivia and Patagonia were presented by Miss I. H. Lenman.

24034—29——43

MOUNDS AND OTHER ANCIENT EARTHWORKS OF THE UNITED STATES[1]

By David I. Bushnell, Jr.

[With 12 plates]

So familiar are we with the present condition of our country, with its great cities and towns and the network of highways extending from ocean to ocean that it is difficult to picture the same region as a wilderness occupied by savage tribes, whose scattered villages were reached by narrow trails through the virgin forests. But such it was, and less than a century has passed since the greater part became definitely known, the courses of the rivers correctly mapped, the mountain ranges discovered and accurately located, and many native tribes visited and identified. Great changes have taken place in recent years; towns have multiplied and expanded; and as one result of the destruction of the forests and cultivation of the soil, especially in the region eastward from the Mississippi, traces of the native villages are rapidly disappearing and the works erected by the people who occupied the sites generations ago are being leveled by the plow and thus obliterated.

The present sketch has been prepared for the purpose of showing the many types of mounds and strange and curious earthworks erected by the native tribes of this part of America, but let us first consider the great wilderness and the widely dispersed groups of settlements encountered by the early explorers and missionaries.

Early in the sixteenth century ships manned by the hardy seamen of England, France, and Spain reached the coasts of the newly discovered continent, and within a generation more pretentious expeditions were fitted out to explore the interior in the endeavor to find gold and treasure and to reach the western ocean. Thus before the middle of the century the Spaniards had traversed the southern lands from Florida to the Mississippi and beyond, while others coming from Mexico had reached the prairies bordering the Missouri. Vessels from France had sailed up the St. Lawrence, and in 1535 the French discovered Hochelaga, a great Iroquoian palisaded town

[1] Published through the courtesy of the National Geographic Society, who released the manuscript and illustrations for use in the Smithsonian Report.

which stood on the site of the present city of Montreal—a name which perpetuates that given to the hill upon which the native town then stood, *Mont Royal.*

As one result of the early expeditions, and undoubtedly there were many of which no record is now available, it became known to the people of Europe that America was occupied by many native tribes who spoke different languages, whose villages differed in form and appearance, and whose manners and customs were influenced to a marked degree by their natural environments. Some had well-developed tribal organizations, were comparatively sedentary, and occupied sites where frail bark habitations had probably been reared through many generations. Near many villages were rather extensive gardens in which were raised varieties of beans, pumpkins, quantities of corn, and other vegetables for food. Other tribes were more roving and each year would travel long distances through the forests or pass with their light canoes along the streams to reach the hunting grounds where game was more plentiful and more easily taken than in the vicinity of their villages. In many localities the entire village would seek the protection of the dense forests against the winter storms. During the frequent journeys away from their more permanent settlements they would establish camps on the banks of streams or in the vicinity of springs or lakes; the sites of these small camps may now be recognized by the occurrence of a few bits of broken pottery, chips of stone, or other camp refuse.

A very careful estimate of the entire native population of that part of the present United States which extends eastward from the Mississippi to the Atlantic shows it to have been approximately 300,000, far less than that of many cities now standing within the same bounds. Certainly a small number of persons to have occupied such a vast region, and as some parts were far more thickly peopled than others wide stretches were without a human occupant and were seldom visited except by roving bands of warriors bound for the villages of their enemies or by hunters in quest of food.

The many tribes are now known to have constituted several well-defined linguistic groups, and of these, at the time of the colonization, the Algonquian was evidently the most numerous. Tribes belonging to this family dominated the coastal plain from Carolina to Labrador, and thus included the native people of Virginia and New England so famed in the early history of the colonies. Kindred tribes lived westward in the vicinity of Lake Michigan. Iroquoian tribes of central New York, who by reason of their highly developed tribal organization formed the league of the Iroquois, were practically surrounded by the Algonquians. The Cherokee were the most important of the detached Iroquoian tribes and lived in the mountainous region of western Carolina and eastern Tennessee and had as

neighbors to the southward members of the Muskhogean stock, including the numerous tribes of the Creek Confederacy, the Choctaw, Chickasaw, and others. Northern Florida was peopled by the Timucua, whose villages were scattered across the peninsula from the Atlantic coast to the shores of the Gulf of Mexico. Siouan Tribes, remotely related to those who lived far westward in parts of the valley of the Mississippi, were found in Virginia and Carolina. Several other families were represented by the people encountered east of the Mississippi, but they appear to have been greatly reduced from their former strength and numbers. Of the many linguistic groups found west of the Mississippi one may now be mentioned—the Caddoan, to which belonged many tribes including the Wichita, Arikara, and Pawnee. Less than 50 years have passed since the great earth lodge villages of the latter stood near the banks of the Platte, west of the Missouri.

With such well-defined groups of tribes who had probably occupied certain regions for many generations, it is reasonable to attribute to them the majority of the ancient mounds and other works of a similar nature encountered within the limits of their territories, although in some instances works standing in a section known to have been occupied by a certain group during historic times were undoubtedly erected by others at an earlier period. However, it is now possible to identify the builders of the great majority of ancient works of various sizes and forms found between the Atlantic coast and the eastern slopes of the Rocky Mountains. And as a consequence of the different manners and ways of life of the people of widely separated parts of the country the existing traces of their ancient camps and villages, their burial places, and the earth and stone structures which were erected by many tribes vary in form and appearance.

Many writers in the past have referred to all tumuli, inclosures, embankments, and other forms of earth and stone monuments left by the native tribes as mounds, which is not only erroneous but quite misleading. The ancient works are of many forms and sizes, and in the present sketch it will be shown that in some localities types are to be found that do not occur elsewhere, and these in many instances present characteristic features proving their builders to have possessed manners and customs radically different from those of their neighbors. In addition to the burial mounds and other structures which were intentionally planned and raised are some which may be termed accidental but which, nevertheless, must be considered with the former. The principal of these are the shell heaps which are encountered along the coasts wherever edible mollusks were obtainable in quantities. The vast accumulations of shells resulted from the gathering of clams or oysters by the native

people, who opened them and either ate them on the spot or smoked and dried them for future use. Many small deposits of shells are visible along the shore, often having been exposed and worn away by the encroaching waters. Some heaps are of great size and were frequented by oyster gatherers for generations, their use probably extending over a period of several centuries. The examination of such sites usually proves of interest, as bits of broken pottery, bones of animals, masses of wood ashes and charcoal, and an occasional complete implement or ornament which had been accidentally lost may often be discovered in contact with the accumulated shells. Although the majority of shell deposits are quite small, others are of vast proportions, and all prove the importance of sea food to the natives who frequented our coasts several centuries ago. The great shell heap on the bank of Damariscotta River, Me., was more than 400 feet in length and 22 feet in depth. The same form of pottery was found in all parts of the great mass, and as the fragments possessed all the characteristics of the earthenware vessels known to have been made by the Algonquian Tribes whose villages stood in New England at the time of the coming of the colonists, and whose descendants may still be found, it is quite evident that their ancestors gathered the oysters and clams which resulted in the accumulation of such vast numbers of shells. Shell heaps dot the entire coast, and many are to be encountered far up the streams. One of the most renowned of these is at the mouth of Popes Creek, which flows into the Potomac on the Maryland shore some miles above Chesapeake Bay. This shell heap once covered an area of 30 acres or more, with a depth in places of 15 feet (pl. 1). The mass was very compact, and in some places it was possible to trace the circular depressed sites occupied by the lodges of the oyster gatherers, with the fireplaces in the center. And how interesting it is to contemplate the scenes so often enacted here, with a cluster of mat or bark covered lodges in the midst of the expanse of shells, with canoes drawn up on the shore, and narrow trails leading through the dense forests to the distant villages.

Ancient Earthworks, Monuments of Another Race

For centuries before the colonization of America by Europeans the country had been occupied by another people, whose strange customs and beliefs caused them to raise many mounds and earthworks, some being of great size and of curious design. In this brief sketch of the ancient monuments, many of which have been destroyed within recent years, the regions known to have been dominated by the several linguistic families will be considered separately, and it will be shown how the different groups of tribes, possessing

as they did different manners and ways of life, erected works of varying forms to serve well-defined purposes.

THE "FORTS" OF THE NEW ENGLAND INDIANS

The native tribes of New England, those to whom the shell heaps have been attributed, did not erect burial mounds although they often constructed low earth embankments, usually accompanied by a ditch and surmounted by palisades, to surround and thus protect their habitations. These were quite small when compared with many similar works erected by tribes west of the Hudson, and now, after the lapse of several centuries, few can be traced. Some were square, others circular, and all designed for protection. These were the "forts" of the natives, so often mentioned by the early historians.

Many small inclosures, burial places, fish weirs, and other indications of Indian occupancy were encountered by the colonists, but with the lapse of time great changes have been wrought and now few of the ancient works remain.

IN THE COUNTRY OF THE IROQUOIS

Westward from New England, beyond the Hudson, lived the Iroquois, so famed in history. About the year 1570 the five tribes, Mohawk, Cayuga, Oneida, Onondaga, and Seneca, formed a confederacy for mutual strength and protection, and in 1722 the kindred Tuscarora, having moved northward from their earlier habitat in Carolina, became the sixth nation of the league of the Iroquois. Although the several tribes just mentioned had occupied or dominated the region for a long period, it is quite evident that others had preceded them and had, during their occupancy of the country, erected many of the small burial mounds near the sites later occupied by the Iroquoian tribes. This does not necessarily imply, however, that the Iroquois did not raise some of the mounds found standing in the country which they so recently dominated. Mounds, all quite small, are found in every county in the State of New York west of a line running north and south through Oneida Lake, and others, more scattered, are encountered east of this line.

The French and Dutch were the first to reach the Iroquois, and many objects derived from these sources have been recovered from sites of the towns which were occupied during early historic times or from burials dating from these years. A mound stood in Chenango County, near the mouth of Geneganstlet Creek, and when opened nearly a century ago revealed a number of burials, together with many stone objects, a ring or band of silver, and a heart-shaped ornament of mica. This stood in the region occupied by the Tus-

carora after the year 1722, and as the discovery of a silver object proves the burial to have been made in historic times it may justly be attributed to the southern tribe. Some member of the tribe may have carried the mica ornament from their ancient home, which was situated near the principal source of supply of that mineral.

Although so few mounds were raised by the Iroquois, and fewer remain to indicate the sites of their early settlements, nevertheless the country once occupied by their many villages formerly abounded in monuments of a far more interesting nature, and what is true of the country of the Six Nations will also apply to the region extending westward along the south shore of Lake Erie and north of the lake to the shores of Georgian Bay, thence eastward to the St. Lawrence—lands occupied by the ancient Erie and Huron, who were related linguistically to the people of the Six Nations.

It was the custom of these people to surround their villages with palisades or with embankments of earth or of earth and stone which were surmounted by a palisade. A ditch is usually traceable at the foot of the embankment. The camps and villages were thus inclosed to afford protection when attacked by their enemies and to prevent the wild beasts of the forests entering and prowling about the settlements, and it is now difficult to realize that so short a time has elapsed since the heavily forested home of the Iroquois was the haunt of bears and wolves, that moose and deer were so numerous, and the beaver could be found building his dam in every stream. So great was the danger arising from many sources that some of the more important sites were surrounded by two, or even more, lines of palisades, one within the other, thus providing even greater protection to the inhabitants. This had evidently been the custom of the people from the earliest days of their occupancy of the rich valleys of which they were so fond; the palisades have now disappeared, although in some instances the post holes are still revealed by the discoloration of decomposed wood. Remains of many embankments are standing, but with the rapid development of the country they are gradually disappearing. It is fortunate, therefore, that about the middle of the last century a large number of the more important sites were surveyed and described, so we may now know of their size and appearance before they were destroyed by the plow.

THE CURIOUS EARTHWORKS OF SOUTHERN OHIO

Burial mounds and traces of fortified camps similar to those already mentioned occur in northern Ohio, the home before the middle of the seventeenth century of Iroquoian tribes. In southern Ohio, in addition to many mounds and remains of walls and embankments raised to protect the camps, are ancient monuments of an entirely different form, and among them are the most remarkable

prehistoric earthworks in America. The great circles, squares, octagons, the long embankments, and many of strange design may be considered the most marvelous earthworks constructed by ancient man, and it is difficult to realize that an American tribe possessed the skill and ingenuity exhibited in their construction. But it is evident that the builders were a sedentary people who cultivated large gardens in the vicinity of their villages, and they must have been comparatively numerous with well-established customs and beliefs, as indicated by the repetition of several highly developed types of works as units of many groups.

The magnitude of some groups is surprising. The works at Newark, Licking County, covered an area of about 2 square miles and consisted of two distinct divisions connected by long, parallel walls. Fortunately the large circle (diameter 1,189 feet), one of the important units of the group, has been preserved and is one of the most interesting prehistoric works in the country. (Pl. 2.) The group at Portsmouth, on the banks of the Ohio at the mouth of the Scioto, was originally far more extended than that at Newark and was of special interest, as the long lines of parallel embankments were continued on the opposite bank of the Ohio where they terminated in a circular work of great size.

These strange works are numerous northward from Portsmouth, up the valley of the Scioto, and along the courses of the smaller tributary streams, and were it possible to solve the mystery of their origin and the meaning of their curious designs it would add a fascinating chapter to the early history of the Ohio Valley.

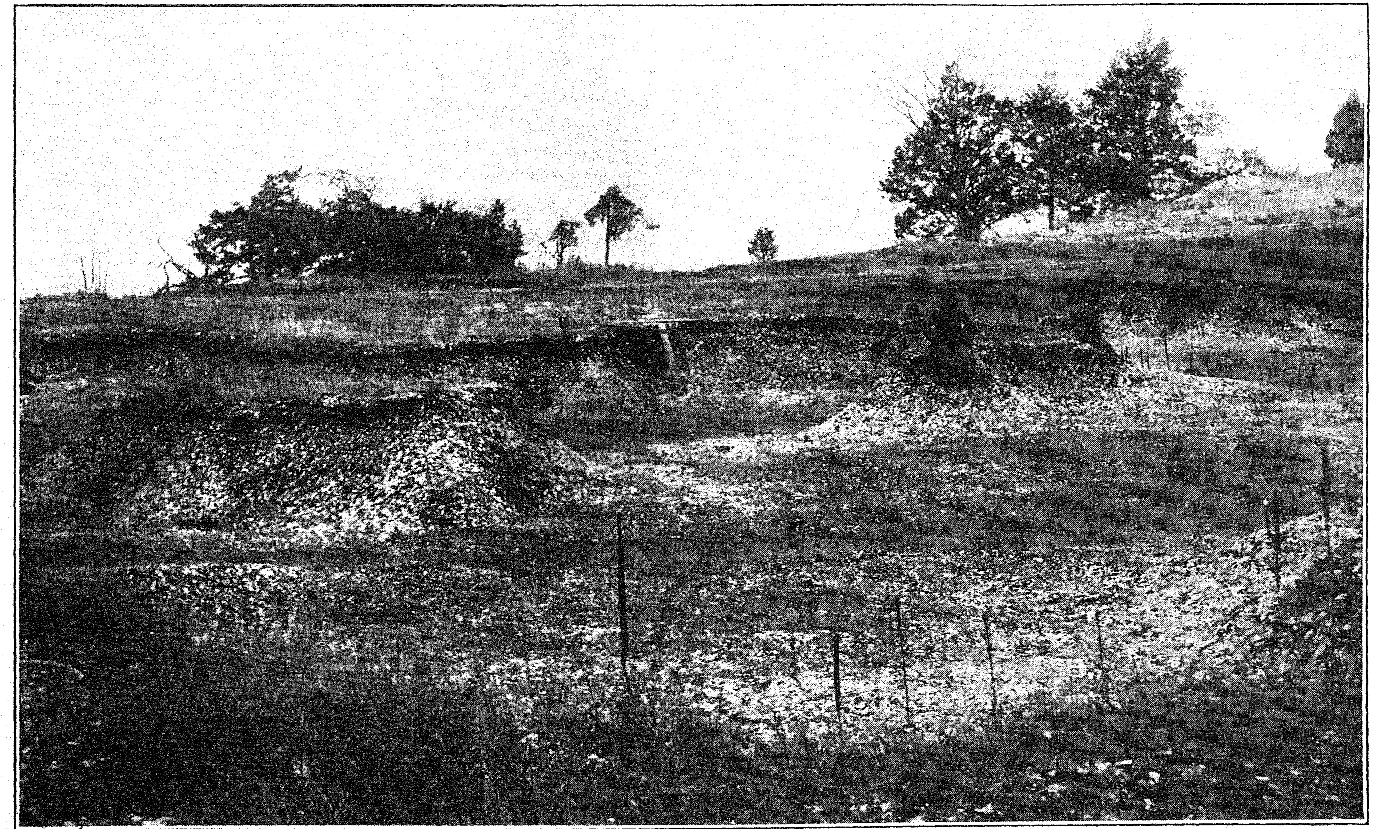
Many small clusters and many isolated works stood in the valley of Paint Creek, a small stream flowing from the west and entering the Scioto just below Chillicothe. (Pl. 3.) Here were burial mounds and fortified camps and perfectly formed groups of the combined squares and circles, designs so often repeated but the meaning of which is not known. A short distance north of Chillicothe, on the right bank of the Scioto, was that most interesting inclosure to which the name Mound City was applied. Of the 24 mounds standing within the walls, some were quite large, one rising 17 feet above the plain and having a diameter of 100 feet. A great number of stone pipes carved to represent birds and animals were recovered from the smaller mound near the southwest corner of the inclosure.

Works of such unusual forms and of such magnitude attracted the attention of the early travelers, who readily recognized them as being very different from any remains then standing in the older settled parts of the country. Pioneers often reared their cabins on the sites of the ancient villages. The first group to be described was that discovered on the left bank of the Muskingum, at its junction with the Ohio, the site of the present Marietta. The account

was prepared by Capt. Jonathan Heart, of the First Regiment, and appeared accompanied by a map in Volume I, No. 9 of the Columbian Magazine, Philadelphia, May, 1787. It was an interesting group of medium size, consisting of two quadrilateral inclosures, within and without which were various mounds and embankments. South of the smaller inclosure, nearer the banks of the Ohio, was a beautiful example of ancient earth mound, very symmetrical and surrounded by a ditch and embankment, a type found elsewhere in the near-by country on both sides of the Ohio.

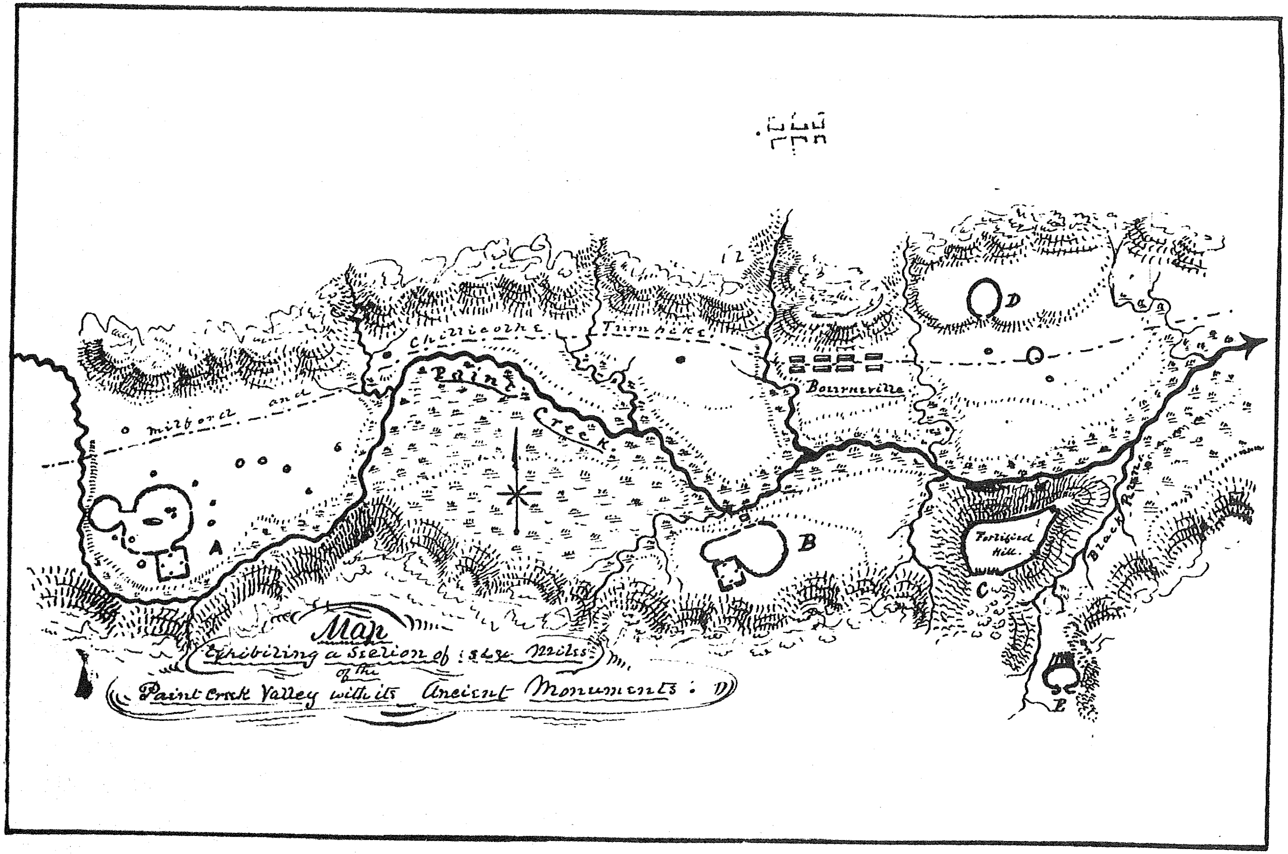
The class of works to which those already mentioned belonged were so skillfully made, of such perfect outline and proportion, that they are usually referred to as ceremonial structures, thus distinguishing them from the more massively constructed embankments which were obviously intended to protect the inclosed villages. Some were quite small, but others would have offered security for thousands of persons. The space within the irregular walls of Fort Ancient, Warren County, Ohio, equaled about 100 acres—sufficient, we are inclined to believe, to have furnished space for the native population of the entire valley. (Pl. 4.) The walls or embankments are more than 3½ miles in length. The area of the inclosed ground at Fort Hill, in Highland County, Ohio, was about 48 acres, and there were many similar sites. The interesting fortification in Butler County, which stood on the west side of the Great Miami River, was about one-third the size of the latter. The wall, formed of stone and earth, was about 5 feet in height and 35 feet in width at base. It skirted the brow of the hill, on both sides of which flowed small streams, a position easily defended. The several openings in the wall and the manner in which they were protected are the unusual features of the fortification. (Pl. 5.)

Burial mounds are often associated with the earthworks, or stand near by, and when examined reveal the methods followed by the ancient people in disposing of their dead. Some were cremated and the ashes deposited in prepared graves, all being eventually covered with earth and the mound thus raised. This is a highly specialized form of burial and is yet another proof of the cultural development of the people who occupied the valleys of southern Ohio many generations ago. Possessing as we do such evidence of the existence of permanent villages, of a rather large population occupying rich and fertile lands where such labor had been expended in the construction of lasting monuments, we are confronted with the question of why they were abandoned. The question may never be answered, but this was probably the early habitat of Siouan tribes, ancestors of the Osage, Omaha, and others of the related group, who when first met by Europeans were living west of the Mississippi, but whose



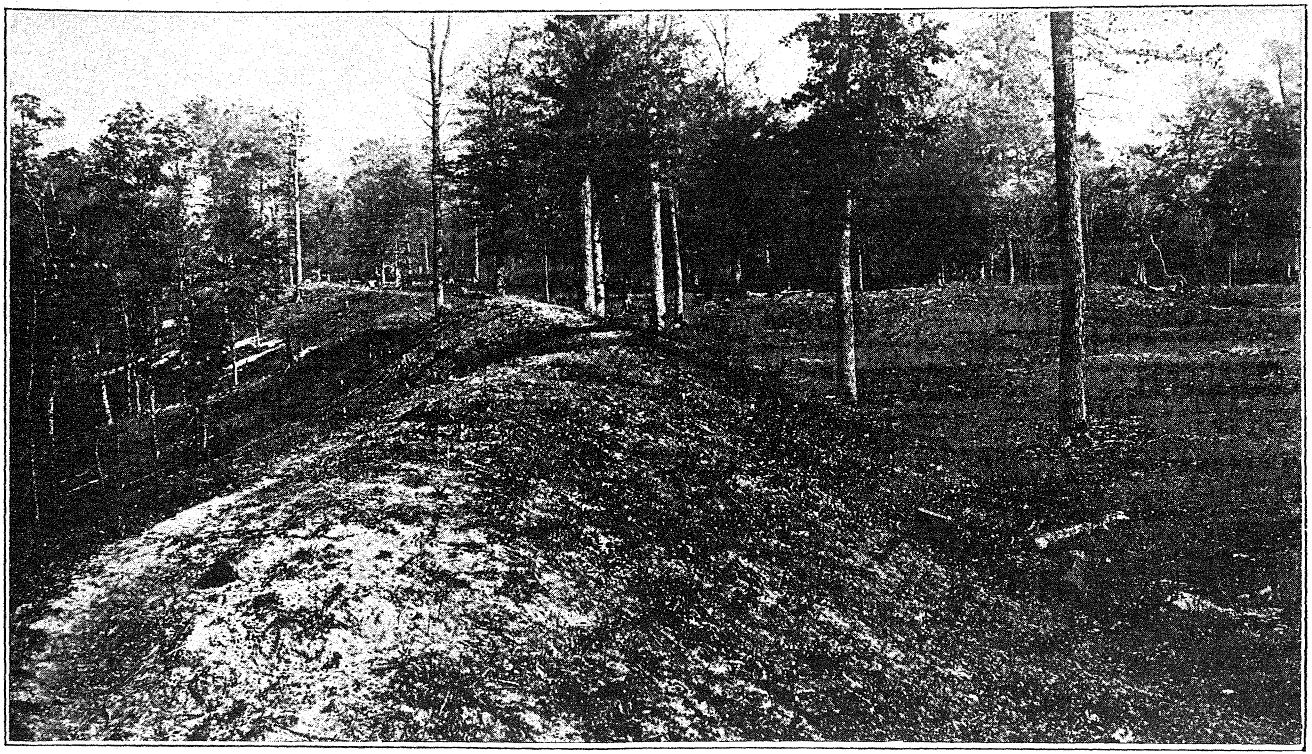
SHELL HEAP, PARTLY REMOVED, AT THE MOUTH OF POPES CREEK, ON THE MARYLAND SHORE OF THE POTOMAC

LOOKING ALONG THE GREAT CIRCLE, ONE OF THE UNITS OF THE GROUP AT NEWARK, OHIO



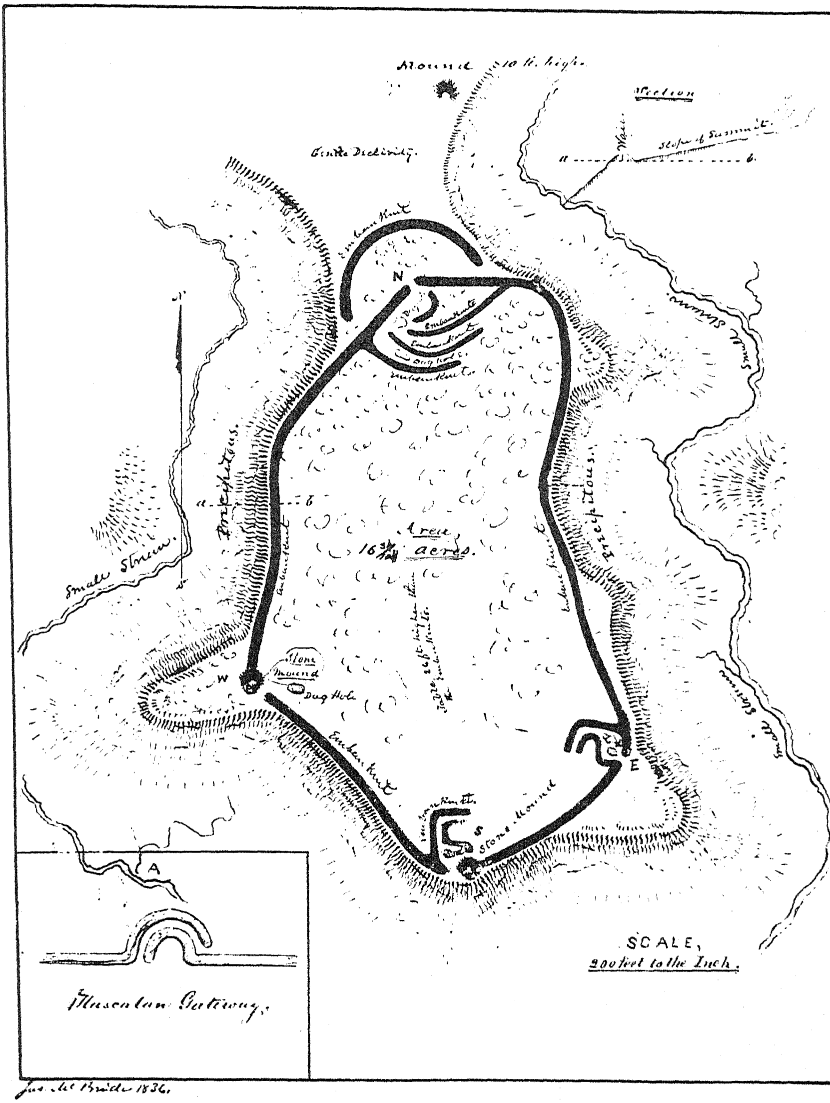
SIX MILES OF PAINT CREEK VALLEY, ROSS COUNTY, OHIO

Drawn by E. G. Squier, 1847. From the original now in the Library of Congress Washington, D .C.



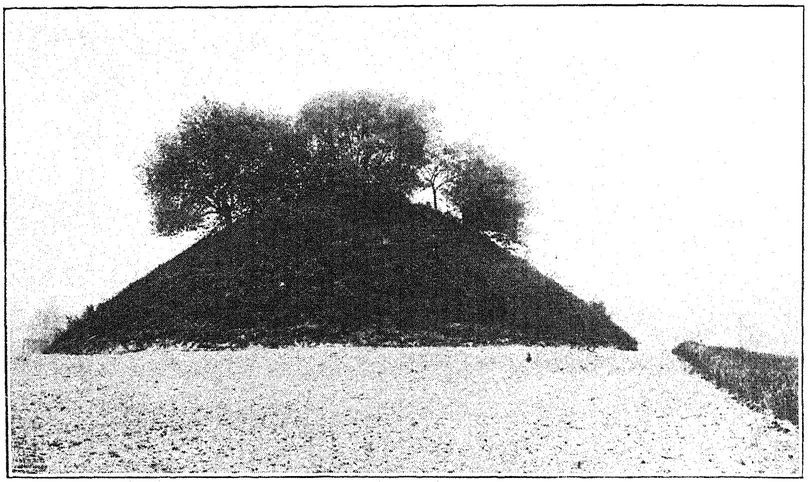
THE EMBANKMENT OF FORT ANCIENT, WARREN COUNTY, OHIO

The entire length of the remarkable wall is 18,712 feet, or more than 3½ miles. Its average height is from 6 to 10 feet, although at one point it rises to about 19 feet. The area within the wall is very irregular in outline and covers approximately 100 acres

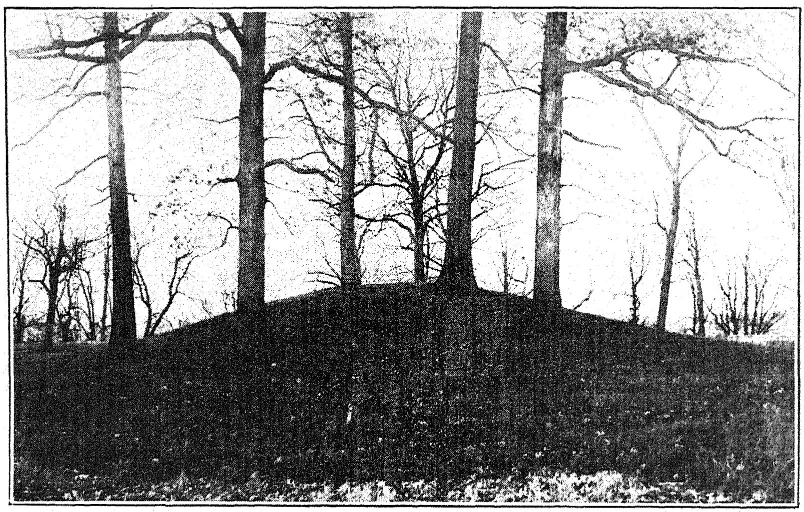


FORTIFIED HILL, BUTLER COUNTY, OHIO

Drawn by James McBride, 1836. Original now in Library of Congress, Washington, D. C.



1. CONICAL MOUND ON WOLF PLAINS, JUST SOUTH OF GALINA, ATHENS COUNTY, OHIO



2. A SPREADING, CIRCULAR MOUND IN THE PARK AT ZANESVILLE, OHIO

ancient home, according to traditions, was in the upper valley of the Ohio. Beautiful examples of circular mounds are shown in Plate 6.

THE SIOUAN TRIBES EAST OF OHIO

Siouan tribes lived eastward from Ohio, across the mountains, and at the time of the settlement of Virginia and Carolina tribes of this stock dominated the region westward from the falls of the James at Richmond. They erected burial mounds of a form not so very different from those reared by the Choctaw of the far south, as will be described later. And it was a mound of this type that Thomas Jefferson opened about the time of the American Revolution and described so minutely in his notes. This particular place of burial stood near the center of a lowland on the right bank of the Rivanna, about 4 miles due north of the University of Virginia, in Albemarle County. It was estimated to have contained the remains of at least 1,000 individuals, and must necessarily have been the burial place of the dead of the near-by village for many years. Northward about 15 miles distant, on the right bank of the Rapidan, was another burial place of the same type—a large mound which contained the remains of several hundred individuals and which may have been even larger than the one examined by Jefferson. Surrounding both mounds were extensive traces of large villages—sites of Monacan towns occupied at the time of the settlement of the colony. It is quite probable these mounds were erected, all or in part, subsequent to the year 1600. Similar mounds, described in early records as "Indian graves," have been discovered in other parts of the surrounding country, and some have been encountered southward as far as Cape Fear in North Carolina.

THE BIRD AND ANIMAL EFFIGIES OF WISCONSIN

The central portion of the valley of the Ohio is justly famed for the number and the magnitude of the geometric earthworks which stood there at the time of the settlement of the country by the pioneers from the east, but in the region between the Mississippi and Lake Michigan are found works of another type scarcely less interesting. These are the effigy mounds, low spreading structures often representing birds and animals; some may have been designed to show human figures with outstretched arms, others are more conventionalized, gradually merged into long embankments, often continuing in parallel rows. These curious works, with few exceptions, occur in the southern part of Wisconsin, from Prairie du Chien at the mouth of the Wisconsin River across the State to near the shores of Lake Michigan. Some of the largest and most varied groups occur in Grant County, bordering on the Mississippi, and northward in the adjoining county of Crawford (fig. 1). The effigies often

occupy the summit of a ridge, where they are placed in such a manner as to suggest a flight of birds with outstretched wings or a number of animals following one after another. Of the individual effigies discovered in Grant County the most noted is that termed the "Elephant Mound" (fig. 2) from its fancied resemblance to an elephant, an animal unknown to the builders of the effigies. It stood a short distance from the Mississippi, south of the village of Wyalusing, and the area it occupied was bounded on three sides by higher ground. Forty years ago, after the surface had been cultivated for some years, this interesting figure measured 4 feet in

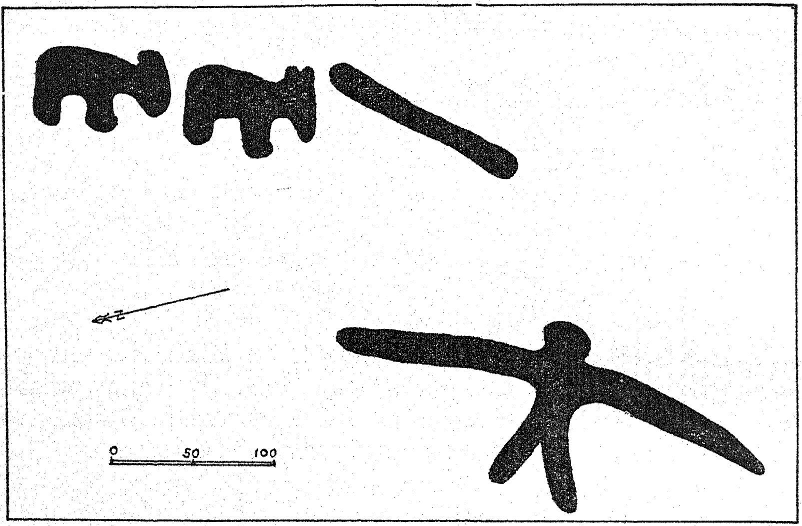


FIGURE 1.—Typical effigy mounds representing two animals and one bird, also one long mound. On the crest of a hill, on sec. 24, T. 8 N., T. 6 W., Crawford County, Wis. The animal figures were each about 80 feet in length and 2 feet in height; the bird was somewhat higher

height and 140 feet in length, undoubtedly reduced in height and greatly spread in length and breadth from its original condition.

Small burial mounds are found in the region occupied by the effigies, some of these undoubtedly containing the remains of persons who assisted in raising the curious works.

Only four effigies have been encountered outside the rather restricted area just mentioned. Of these, two are in Ohio and two in Georgia. The two in Ohio are the great Serpent Mound in Adams County, and the strange figure termed "the Alligator," in Licking County. The two figures in Georgia represent birds with outstretched wings and were formed of stones, thus differing from the other examples.

SMALL MOUNDS AND LONG EMBANKMENTS NEAR THE HEADWATERS OF THE MISSISSIPPI

As we continue westward from Wisconsin to the headwaters of the Mississippi and beyond we encounter long embankments, similar to although in many instances much more extensive than those associated with the effigy mounds already described. They are found in many places in Minnesota, northward in the adjoining Provinces of Canada, in North Dakota, and some southward. Many are several hundred feet in length and 15 to 20 feet in width at base. In many instances they are placed parallel to one another; others form irregular inclosures which would have served poorly as works of defense,

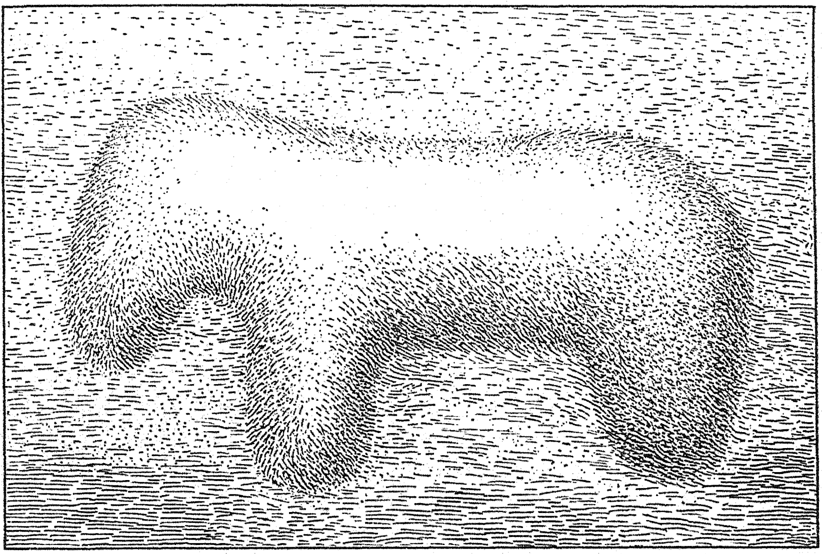


FIGURE 2.—The "Elephant Mound," Grant County, Wis., as it appeared some years ago. It then measured 4 feet in height and its extreme length was 140 feet. It was undoubtedly intended to represent a bear, with its head to the south. The surface has been plowed for many years

and it is difficult to offer a plausible theory of the purpose for which these ancient embankments were erected.

In central Minnesota, the home of the Dakota when they were first encountered by the French, are innumerable small burial mounds which may justly be attributed to these tribes. The mounds stand in large groups on the shores of lakes or banks of streams, often placed in long rows, then again in irregular clusters, as the nature of the ground permitted. When excavated they reveal small bundles of human bones; it was the custom of these people to remove the flesh from the bones before the latter were placed in the graves. In after years, when the Ojibway gained control of the region about the headwaters of the Mississippi, a region of dense pine forests and

many lakes, they continued to use the ancient mounds as burial places for their dead, placing the bodies in an extended position near the surface. This is the simple explanation of the two distinct forms of burial discovered in the mounds, and what is true in Minnesota is equally true in other sections of the country as regards the use of the same mounds by one or more tribes who possessed different manners and customs. But some tribes, especially in the South, had several methods of disposing of their dead, as indicated by the discovery of various forms of burials in the same mound. These often occur in contact with one another and were evidently placed there by the same people at about the same time.

THE GREAT CAHOKIA MOUND, NEAR THE CENTER OF THE MISSISSIPPI VALLEY

Innumerable mounds of various forms and sizes, erected by many tribes to serve different purposes, are scattered throughout the valley of the Mississippi, but the most imposing groups stand, or rather stood, on both sides of the Mississippi a few miles below the mouth of the Missouri. Here appears to have been the central gathering place of the tribes of the valley, where they were wont to come together and where they had dwelt through many generations. In the rich lowlands opposite the present city of St. Louis they raised the great truncated pyramid, now designated Cahokia Mound, which rises 100 feet above the plain, extends 1,080 feet from north to south, and more than 700 feet from east to west (pl. 7), a remarkable structure to have been reared by primitive man with the simplest of methods and the crudest of implements. It is an imposing structure and should be carefully preserved as a monument erected by a people of another race before the central valley of the continent was known to Europeans. The ancient people, undoubtedly coming from the south and possibly from as far away as Mexico, chose this spot as the site of their greatest structure. How long they remained and what causes impelled them to abandon the region may never be determined, but their descendants were probably some tribe or tribes known in historic times living away from their earlier habitat.

The massive work stands near the center of the plain, surrounded by 70 or more lesser mounds, some of which rose more than 40 feet above the natural surface. This principal group was flanked by others to the north, south, and west, the latter having been on the summit of the high cliff overlooking the Mississippi from the west, an area now within the city of St. Louis. In addition to the many mounds forming the four distinct clusters, which should be regarded as four units of a greater group, were scattered mounds along the brow of the bluffs bordering the lowlands on the east, but similar artificial works are found overlooking the great river throughout its

course. Of the great number of mounds that formerly stood in the vicinity of Cahokia, few remain in their original condition, many have entirely disappeared within the past half century, and others have been greatly reduced by the plow, now rising only as low swells above the level surface of the plain. Cahokia, the great mound, stands in practically the same condition as when first discovered. Parts of its surface have been cultivated, but not sufficiently to injure or modify its contour which is so clearly defined when viewed from the east.

Cahokia was erected with its four sides facing the cardinal points, as were the smaller rectangular mounds of the group, and on the south it slopes from the summit plateau to the lower terrace which continues in a narrow graded way to the level of the plain. This must have served as the main approach for those ascending from the surrounding lowland to the terrace or upper plateau, undoubtedly the scene of many and varied ceremonies by the occupants of the land long before it was invaded by the people of another race.

Although Cahokia has never been extensively excavated, its artificial nature is beyond question. It was raised entirely by man by primitive methods, and should now be preserved by the State as a lasting monument. It occupies a position in the Mississippi Valley comparable to that of the pyramids of Egypt in the Valley of the Nile and the massive structures in the Valley of Mexico. The destruction of Cahokia would prove an irreparable loss which must be averted for the benefit of future generations.

As mentioned, Cahokia and all the lesser rectangular mounds of the surrounding group were oriented with their sides facing the cardinal points. This appears to have been the rule without exception, and the accuracy with which they were constructed makes it quite evident that their builders had knowledge of the North Star, which served as the guide in their labors.

When this region was first visited by Europeans during the latter part of the seventeenth century it was occupied by Algonquian tribes, the Cahokia and related Tamaroa, belonging to the Illinois confederacy. They were a roving people and had probably only recently arrived on the bank of the Mississippi. They were in no way associated with the erection of the great mounds standing nearby, although many of the burials discovered eastward from the base of Cahokia may justly be attributed to these later occupants of the land.

Some miles eastward from the great mound groups, about 3 miles northward from Lebanon, St. Clair County, is a large rectangular mound rising above the surrounding level plain. It is placed with its angles facing the cardinal points, thus differing from all similar

units of the Cahokia group, but resembling in several respects the great Etowah mound standing in Bartow County, Ga.

SMALLER MOUNDS IN THE SOUTH RESEMBLE CAHOKIA

Many works farther south give the impression of having been erected by people related to those who raised Cahokia. Quite similar in outline although small in comparison, mounds in Jefferson and other counties in Arkansas, in Louisiana, Mississippi, Alabama, and Georgia, appear to have been built by related tribes or those who possessed similar manners and customs, although distinct from the northern tribes. To these tribes should be attributed the mounds in Bartow County, Ga., southeast of Cartersville near the banks of Etowah River. This is known as the Etowah group. The large mound has an elevation of 61 feet above the low ground bordering the river, and its base measures 380 by 330 feet, far less than Cahokia (pl. 8). On one side is a curious incline which does not reach the summit. There were formerly many smaller mounds in the vicinity of the large work, but all have disappeared. This was evidently the site of a large town, an influential center of population, and may have been visited by De Soto during the year 1540 when the Spaniards traversed the southern country, but now little remains to indicate the importance of the site.

THROUGH THE VALLEY OF THE MISSOURI AND ELSEWHERE WEST OF THE MISSISSIPPI

Before discussing the mounds of the southern country, it will be of interest to refer to the works found westward along the banks of the Missouri, beginning at its junction with the Mississippi.

The small mounds quite plentifully distributed through this region are of several types and were probably erected by various tribes at different periods during their migrations through the valley. Within historic times, and probably for some years preceding the coming of the French, the Missouri Valley was the home of Siouan Tribes, the Osage and Kansa belonging to this linguistic family. But they should not be regarded as the builders of the majority of the mounds, although they may have erected some. Many mounds could be attributed to any one of several tribes, but another class of works belongs to a highly specialized type, few examples of which have been discovered outside this region. These are the burial mounds, each of which contains a large inclosure constructed of stone, usually rectangular, well built and having often an opening or passage on one side. (Pl. 9.) A few scattered tombs of this type have been encountered farther north near the Mississippi, and some have been discovered east of the river in Illinois. They are found up the Missouri beyond the mouth of the Kansas River, but are far less

numerous than eastward from that point. The objects recovered from these mounds are very crude, few in number, and do not aid in the identification of the builders of the graves. It is believed they were constructed by a tribe, or possibly by several related tribes, while they were migrating through the valley, making long stops on the way, as was the usual custom of many tribes when moving from one section of the country to another, but whether they were going from east to west or west to east has not been determined.

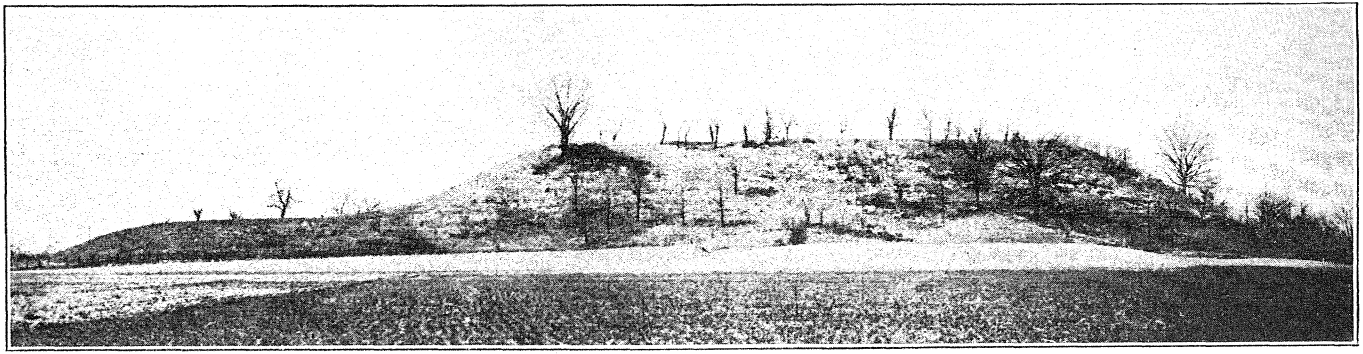
Small, low, spreading mounds exist in vast numbers west of the Mississippi and south of the Missouri. They occur in extensive groups, a hundred or more often being found within a limited area. As an indication of their great number it will suffice to say that 860 were once counted within a space of less than 10 square miles in Dallas County, Mo., forming several large groups with smaller clusters between. They are encountered as far south as the coast of the Gulf of Mexico, through Louisiana and Texas, and to add to the mystery they are not found east of the Mississippi. All were undoubtedly raised by man, or rather resulted from man's work. Some may have been places of burial, similar to the innumerable small mounds standing in the northern section of the Mississippi Valley, although they are more ancient and all traces of the human remains have disappeared from them. Others are evidently the remains of earth-covered habitations which stood generations ago; the frame, having fallen through decay, allowed the earth covering to settle and form a low, spreading mound, slightly elevated above the surrounding surface. Considering the great number of these small mounds, their wide distribution, and the usual lack of implements or bits of native pottery in the vicinity of the groups, their origin remains one of the unsolved mysteries in connection with the activities of the native tribes of this part of North America.

Within the past half century large earth-covered lodges were occupied by the Pawnee, Mandan, and other tribes in the upper Missouri Valley. Farther down the valley were ruined villages of the same people, many of which had been inhabited during the eighteenth century. (Pl. 10.) All were composed of similar structures, some being more than 40 feet in diameter, flattened, dome shaped, made of a heavy frame covered with thatch and a mass of earth and sod. In some instances the floor space within the circular wall had been excavated several feet; in others only a slight excavation, if any, had been made. The frames decayed and fell away, and where the excavated space was not sufficient to hold the earth and sod which had served to cover the lodge a low mound resulted, quite similar in appearance to many found south of the Missouri.

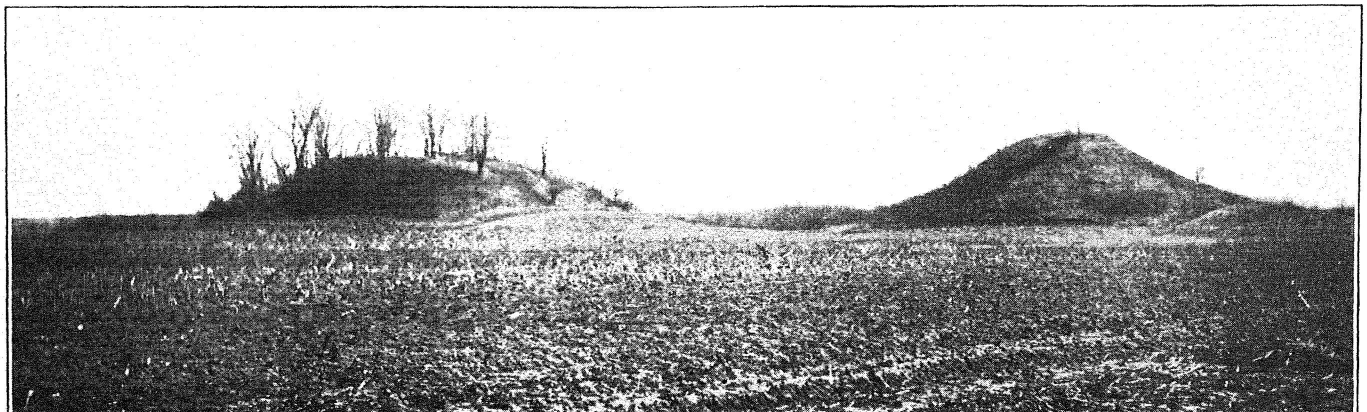
The curious mounds just mentioned must not be confused with the small earth circles which also occur in groups, many of which are found east as well as west of the Mississippi. They have been discovered in southern Illinois, parts of Kentucky and Tennessee, and elsewhere east of the Mississippi; also across the river in southeastern Missouri. Each of the small circles or slight depressions indicates the site of an ancient habitation, possibly of a lodge, the walls of which were composed of small interwoven branches or vines covered with several inches of plastic clay which, when dry, formed a substantial wind-proof wall. Where a number of similar circles are found together, often closely grouped and of uniform size, it is evidence of the existence at some time in the past of a native village. Many such settlements were surrounded by a ditch and an embankment which was probably surmounted by a palisade, and although the latter has long since disappeared the ditch and embankment may be traced, unless leveled by the plow. Many villages on the banks of the upper Missouri were so protected within the past century, a continuation of a custom once practiced throughout the greater part of the country.

A great number of mounds have been excavated in southeastern Missouri and the adjoining part of Arkansas, and the majority have revealed quantities of earthenware vessels of many shapes and styles of decoration. They do not appear to be very ancient, and a large proportion were probably fashioned by the tribes found occupying the country by the early French explorers. The mounds were the burial places belonging to the people of the near-by villages, and the discovery of such quantities of pottery vessels in the mounds proves the custom of the people of depositing many vessels in the graves with their dead.

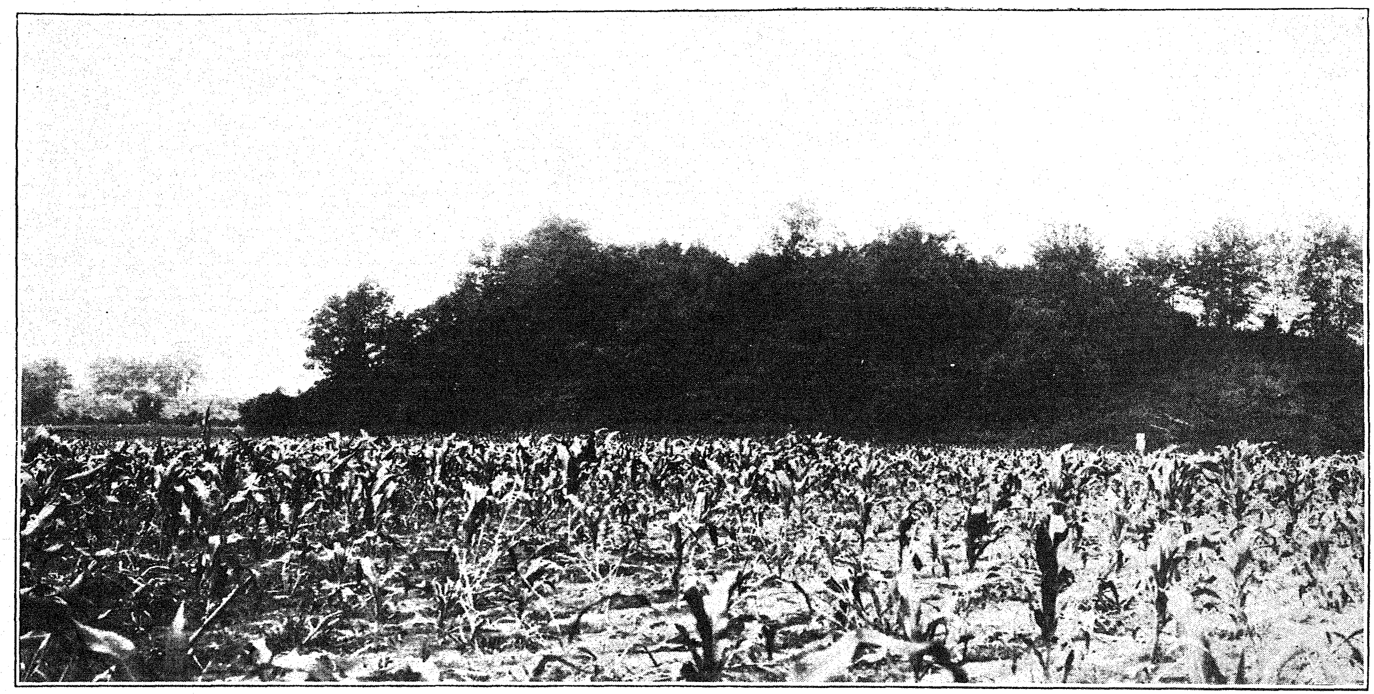
Careful examination of the mounds of Louisiana and Texas would undoubtedly reveal much of interest and would assist in tracing the line of migration of many southern tribes, but unfortunately very little work has been done in that part of the country. Ancient trails traversed the region and served to connect the west and southwest with the Mississippi Valley. There is no reason to doubt the movement of tribes from the southwest into the country bordering the Mississippi and eastward, and eventually it may be shown that Cahokia, Etowah, and other works of the same type owe their origin to a tribe or group of tribes whose earlier habitat had been south of the Rio Grande. The shell and copper objects found in the Mississippi Valley, at the Etowah Mound, and elsewhere, which bear incised decorations so like those employed by the ancient Mexican artists, were undoubtedly made by some who had knowledge of the works of the latter.



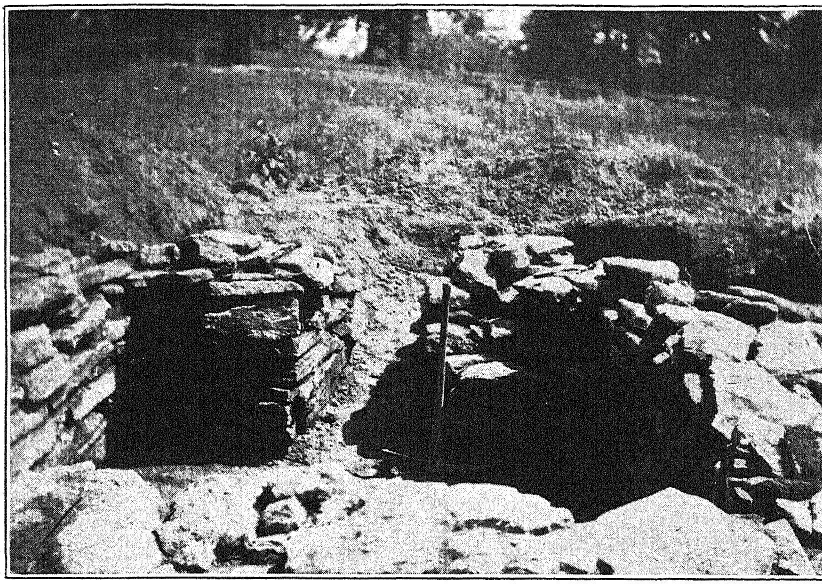
1. CAHOKIA FROM THE EAST



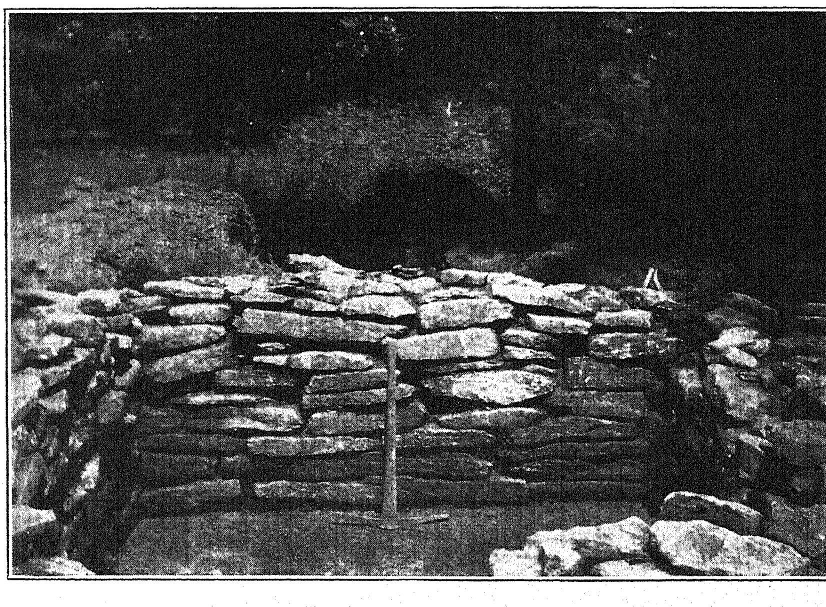
2. MOUNDS BELONGING TO THE CAHOKIA GROUP, JUST SOUTH OF THE GREAT WORK



ETOWAH MOUND, SOUTHEAST OF CARTERSVILLE, BARTOW COUNTY, GA.

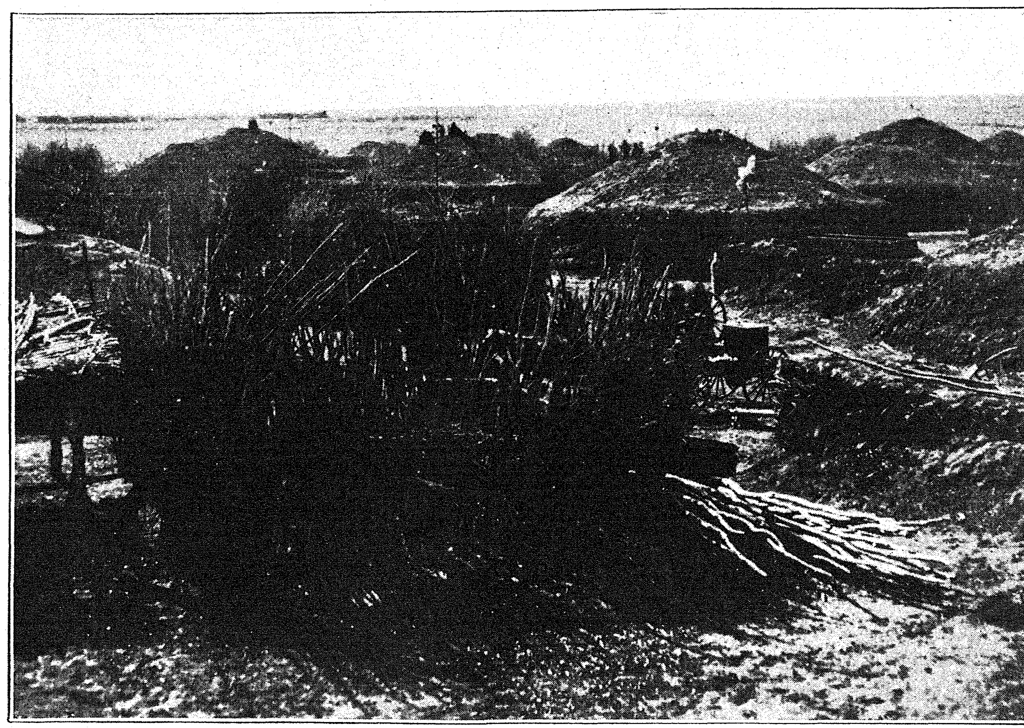


1. Showing entrance to the inclosure



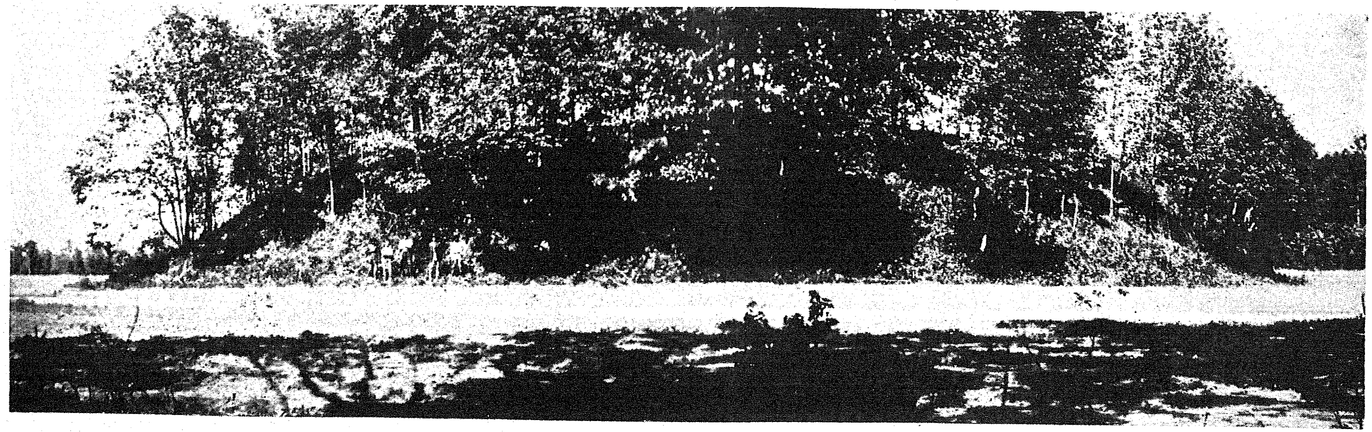
2. Showing wall opposite entrance

STONE INCLOSURE IN A MOUND ABOUT 4 MILES NORTH OF KANSAS CITY, MO. MOUND ABOUT 45 FEET IN DIAMETER; INCLOSURE APPROXIMATELY 8 FEET SQUARE



PAWNEE VILLAGE WHICH STOOD ON THE LOUPE FORK OF THE PLATTE, IN EASTERN NEBRASKA

(Photograph by W. H Jackson, 1871



THE NANIH-WAIYA MOUND, WINSTON COUNTY, MISS.

This large mound is known to all the Choctaw, and is regarded by them with awe as a place of mystery

MOUND ON THE SITE OF THE UPPER CREEK TOWN OF KOLOMI, ON THE LEFT BANK OF TALLAPOOSA RIVER, MONTGOMERY COUNTY, ALA.

THROUGH THE PINELANDS EAST OF THE MISSISSIPPI

South of the Ohio was a region where the wants and requirements of a primitive people were easily fulfilled, where game was plentiful, and the many streams afforded easy passage for canoes. Here among the hills and valleys of the present States of Kentucky and Tennessee lived tribes whose manners and ways of life differed, and consequently the traces of their villages and burial places vary in form and appearance. All were not here at the same time, and centuries must have elapsed since the region was first entered by man. The first comers were followed by other tribes speaking different languages and possessing other customs.

Small groups of mounds are quite numerous along the watercourses, many were places of burial, and others served as elevated sites for habitations or other structures. Many when examined reveal several tiers of stone-lined graves placed one upon another and all covered with a mass of earth, thus forming a mound. The graves are similar to those which existed in vast numbers in the same region, forming the stone-grave cemeteries which often covered many acres, as did those in the vicinity of the city of Nashville. It is not possible at this time to refer to all of the many mound groups, indicating the positions of ancient settlements in the valleys of the Tennessee, the Cumberland, and other streams, but a few may be mentioned. One interesting cluster stands in the national cemetery, Shiloh, on the banks of the Tennessee, and fortunately the mounds will thus be preserved. The largest work in the valley of the Tennessee is near Florence, Ala., a few miles south of the northern boundry of the State. It stands near the bank of the river, and the site was protected by a crescent-shaped embankment touching the river bank both above and below the mound. The latter, when surveyed nearly a century ago, appeared to have been roughly hexagonal in outline, a remarkable feature if it actually existed as shown on the old sketch.

Evidently at some time during the occupancy of this region by native tribes it was necessary for them to protect their villages and secure themselves against attacks by their enemies. Many ancient sites in Tennessee and some in the country southward, were protected by walls and embankments, with ditches and probably with palisades. A strongly protected village, covering many acres, stood at the junction of two forks of Duck River, Franklin County, Tenn. (Fig. 3.) Here artificial walls, ditches, and mounds supplemented the protection afforded by the high cliffs which rose above the waters. The site is quite similar in appearance to others found northward, across Kentucky, scattered through eastern Indiana and western Ohio, near the south shores of Lake Erie, and thence eastward to near the Hudson. Were the builders of the widely scattered works related, and

do they serve to indicate a line of migration from the southward?—questions which may be solved but which are not to be answered now.

MOUNDS ERECTED BY THE MUSKHOGEAN TRIBES

As mentioned at the beginning of this sketch, Muskhogean tribes were found occupying large and rather permanent villages by the Spaniards when they traversed the southern pinelands from the Atlantic to beyond the Mississippi during the first half of the six-

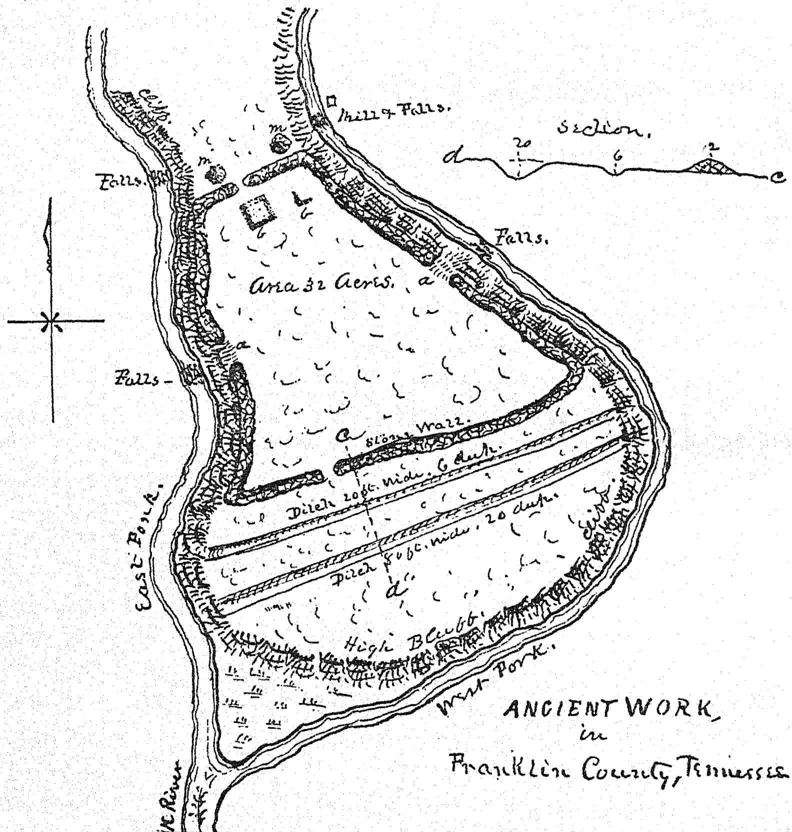


FIGURE 3.—Fortified site in Franklin County, Tenn. This plan was made during the early part of the last century and shows the use of stone walls, mounds, and ditches to supplement the protection afforded by the high cliffs. Original sketch now in Library of Congress, Washington, D. C.

teenth century. Villages were then discovered near where they were destined to remain for three centuries as some tribes continued to dominate the region for that long period, and it is not possible to surmise how many generations had lived and died there before the coming of the invaders. Being able thus to trace and identify the occupants of the country through several centuries, it is permissible to attribute to the same people the great majority of the ancient mounds

standing in their territories, but, as will be shown later, all were not erected for the same purpose. The manners and ways of life of the people of the several groups of tribes differed, and this caused a difference in the use and origin of the mounds, many of which mark the sites of villages of centuries ago.

The Choctaw, ever friends of the French colonists, claimed a large part of the present State of Mississippi and of western Alabama. They had numerous villages, cultivated the soil, and were rather sedentary in their habits. They had a strange method of disposing of their dead, and the final act, a year or more after death, was to place the bones, from which all particles of flesh had been removed, in a basket or pack, and on an appointed day all would assemble with their dead, the baskets and packs would be placed one upon another on the ground, and all would be covered with a mass of earth. Later other remains would be placed on the same tomb, more earth would be added, and in time a mound of considerable size would result. Many of the small mounds now standing within the limits of the ancient Choctaw territory owe their origin to this curious tribal custom. Years have now passed since the burials were made, all material of a perishable nature has disappeared, the baskets and mats which contained the remains have decayed and fallen away, and the bones have all but vanished. The earth has settled and formed a compact mass, making it difficult to discover the nature of the mound and to recognize it as having been the last resting place of many dead.

A large mound standing in Winston County, Miss., is known to all the Choctaw as Nanih-Waiya. (Pl. 11.) It rises some 20 feet above the original surface, having a length from northwest to southeast of more than 200 feet, less in width, and has a rather level summit plateau. Several smaller mounds stood in the vicinity, and all appear to have been surrounded partly by an embankment and partly by a small stream. It is the belief of the Choctaw that a passageway leads downward from the summit of the large mound and, according to one of their traditions, their ancestors many generations ago emerged through this opening from the depths of the earth. And although this happened so long ago and they later scattered in all directions, they have ever remembered the hill from the summit of which they first beheld the light of the sun. The site appears to be very ancient, and the large mound was probably erected before the coming of the Choctaw.

Large groups of similar mounds are encountered along the courses of the Black Warrior and Tombigbee Rivers, well within the limits of the old Choctaw country. Several such groups, one including 40 small mounds, occupy a rather restricted area in Morengo County, Ala., and all were probably erected by the Choctaw. Not far north-

ward, east of the Black Warrior River near the town of Moundsville, is the most important group of earth mounds south of the Ohio, quite unlike those erected by the Choctaw. Some of the most interesting stone objects yet found in the United States have been recovered from these works, and the question is suggested, Could they have been constructed by a people related to those who reared Cahokia and Etowah? Future discoveries at Cahokia may serve to answer this most interesting question.

The upper Creek towns were eastward from the country of the Choctaw and centered about the junction of the Coosa and Tallapoosa Rivers, in the vicinity of the present city of Montgomery, Ala. (Pl. 12.) The settlements of the lower Creeks were in the valley of the Chattahoochee. Mounds, single or in groups of two or more, occur throughout the region, and undoubtedly every such occurrence is proof that a village once stood in the vicinity, and many of the towns were occupied within the last century. It was the custom among the Creeks to erect their town house on the summit of an artificial mound, one raised for that purpose, and a short distance away on another artificial mound stood other public buildings. The space between the mounds, or rather the two sites, likewise belonged to the village as a whole.

In the south, where the river banks are low and are frequently overflowed, it appears to have been a custom of the people to erect mounds to serve as places of refuge, dry spots in the midst of their inundated villages, and many mounds of this sort are found in the old Creek country.

Among the Cherokees a single structure was erected in every village, a town house which stood on the summit of an artificial mound. At the Cherokee town of Cowe, which in 1776 stood on the banks of Little Tennessee River, about the mouth of Cowee Creek, in the present Macon County, N. C., the town house crowned an earth mound some 20 feet in height. The structure rose 30 feet higher, making the peak of the roof about 50 feet above the lowland. In the year 1761 the town house at Chote, one of the most important Cherokee towns, then standing in the present Monroe County, Tenn., opposite the ruins of Fort Loudon, occupied the summit of a mound, evidently one of a group examined a few years ago. When this particular mound was excavated, a number of burials were discovered near or resting upon the original surface, and just west of the center was a circular stone wall about 9 feet in diameter and rising about 2 feet above the natural surface. Within this inclosure were 12 skulls and many disconnected bones. This discovery at once suggests the traditional account of the ceremonies attending the erection by the Cherokee of mounds to serve as sites for their town houses.

It was related some years ago by an old member of the tribe to the late James Mooney, and was in part:

> The town house was always built on the level bottom lands by the river in order that the people might have smooth ground for their dances and ball plays and might be able to go down to water during the dance. When they were ready to build the mound, they began by laying a circle of stones on the surface of the ground. Next they made a fire in the center of the circle and put near it the body of some prominent chief or priest who had lately died—some say seven chief men from the different clans. . . . The mound was then built up with earth, which the women brought in baskets. . . .

This explains the origin and use of many of the larger mounds in the southern country.

In addition to the mounds just mentioned, other types of works are encountered in the same valleys. Some were burial places; others resulted from the gradual accumulation of camp refuse, such as wood ashes, broken earthenware vessels, bones of animals which had served as food, as a result of the restricted area having been occupied as a camp site for many years, possibly for generations. The origin of such elevated sites should be considered accidental rather than intentional, although they often served as burial places for the dead.

Mounds are found in eastern Georgia and are very numerous on the mainland and islands below the mouth of the Savannah. Many on the islands of St. Catherine, Ossabaw, and Sapelo have been examined, and, together with traces of native settlements, appear to be quite old. Few objects of European origin are discovered in contact with native artifacts, and it is evident that the presence of Spanish missions, established along the coast before the close of the sixteenth century, quickly influenced the manners and ways of life of the native people, many of whom moved inland and sought new homes. However, some small mounds in this region owe their origin to the later occupants of the coasts, and a small structure which stood a few miles south of the Savannah River, in Chatham County, Ga., covered a single human skeleton resting upon the original surface, and with it had been placed implements of stone and other objects of native workmanship, together with a sword of European make, the latter proving the burial mound to have been erected within historic times.

STRANGE WORKS IN FLORIDA HIDDEN BY THE DENSE VEGETATION

Southward were the Timucua tribes, whose many villages at the time of the coming of the Spaniards were scattered throughout the northern half of the peninsula of Florida, north of Tampa and Cape Canaveral. Many interesting mounds stand within the bounds of the Timucua country of four centuries ago, and it is quite evident the builders followed certain established rules and customs while

erecting many of the larger works. Some when examined show a thick stratum of sand, artificialy colored red or a pinkish hue by the admixture of red oxide of iron, deposited over the entire group of burials before the superimposed mass of earth and sand had been added. This must necessarily have been a long and tedious undertaking and reveals the care with which they toiled when providing a resting place for their dead.

More than a century and a half ago the large works near the banks of the St. Johns River, Fla., attracted the attention of travelers, and the name Mount Royal was applied to a large mound just below Lake George in the present Putnam County. It rose 16 feet above the original surface and had a circumference of some 555 feet. It was an interesting work, and to add to the great importance of the site an avenue extended from the mound to Lake George, a distance of about a half mile and was from 12 to 20 yards in width, bordered on each side by an embankment about 2½ feet in height. The mound was examined and many burials were discovered, but nothing of European origin was encountered. This must have been an important center of population before the Spanish conquest of the peninsula, where interesting scenes were enacted within the parallel embankments leading from the great artificial mound to the shores of the lake.

It is quite evident and easily conceived that many, if not a great majority, of the large mounds encountered along the low, marshy coast, were raised by the occupants of the region to serve as elevated sites for habitations and other structures of the native villages. This is clearly indicated by a passage in the narrative of the De Soto expedition. When that daring leader and his numerous party entered Tampa Bay early in the year 1539, they discovered the Timucua village of Ucita on the shore of the bay where several large mounds had been erected. On the summit of one stood the temple, probably a structure covered with a thatch of palmetto, and surmounted by a carved figure of a bird with "gilded eyes." Habitations had been reared on other near-by mounds. Ucita may not have differed in appearance from many native villages then standing throughout the peninsula.

Rather low spreading mounds of sand often standing near the larger structures, appear to have been the burial places for the dead of the village. Instances have been recorded in the vicinity of Tampa Bay, and elsewhere, of the discovery of two forms of burial in the same mound revealed in distinct strata, suggesting that the site had been occupied during two or more periods by tribes whose manners and ways of life differed. Such sites are worthy of the most careful study.

Continuing southward from the land of the Timucua, on the low sandy keys off the coast of the Gulf of Mexico, are the mounds of sand and shells, with the great intervening and connecting canals and lagoons, constructed centuries ago. Some are very extensive and reveal a degree of skill possessed by their builders that is quite remarkable. But who were the builders of these ancient works now hidden by the luxuriant growth of semitropical vegetation? Another unsolved question.

At some time in the future when many old sites not only within the United States but on the islands of the West Indies, in Mexico, and other parts of America, have been carefully examined, a comparison of the material discovered will undoubtedly reveal the route of migration of many tribes who occupied parts of the United States within historic times, and thus lead to an identification of their older habitat. But much remains to be accomplished before we can hope to arrive at any definite conclusions.

GEOCHRONOLOGY, AS BASED ON SOLAR RADIATION, AND ITS RELATION TO ARCHEOLOGY [1]

By Gerard De Geer

In the American journal Science for 1920 mention was made of my plan for investigating certain laminated clays in North America. During a previous visit to that country in 1891 I had noticed, in several places, laminated clays, similar to late glacial melting sediments in Sweden; these I had found, by long continued investigations, to represent the annual deposit from the melting water along the border of the retreating ice edge. (Fig. I.) With the aid of a graphic method for the comparison of the sharply marked annual layers or varves, I had succeeded in identifying such varves from one point to another, and ultimately worked out a systematic plan for the elaboration of a continuous time scale. (See p. 690.) This was mainly carried out in 1905–6 on the basis of field measurements made with the assistance of a number of able young geologists. During the following year this standard scale was completed at many points. I thus succeeded in tracing, step by step, the recession of the ice edge and the immediately following progress of the clay varves over one region after the other, until the whole line from the south to the center of Sweden had been traced.

As might be expected, the lowest and oldest clay varves were found deposited in the southern extremity of the land, while the great ice sheet covered the whole of the rest. By following the progress of the clay, step by step, the whole series was built up, thus forming a continuous and exact time scale for the last recession of the ice through Sweden up to a certain year, when a great ice-dammed lake in central Sweden was drained off, depositing a very thick annual varve. This year was chosen as representing the very end of the late glacial epoch. (See map on p. 691.)

For many years I tried in vain to find some means of determining the length of the succeeding post-glacial epoch proper, until one of my most successful assistants, R. Lidén, discovered in the northern part of Sweden annual varves for that epoch also. Of these varves I measured in one section at the Indal River rather more than 3,000,

[1] Reprinted by permission from Antiquity, Vol. II, No. 7, September, 1928.

but it was along the Angerman River that Lidén himself, quite independently, succeeded in finding and working out practically the whole of the post-glacial varve succession by a careful and painstaking correlation of a long series of sections, giving the total length of the post-glacial epoch as about 8,700 years. What made his work especially important is that there seems to be no other place in the world, not even in Sweden, where there is a possibility of finding

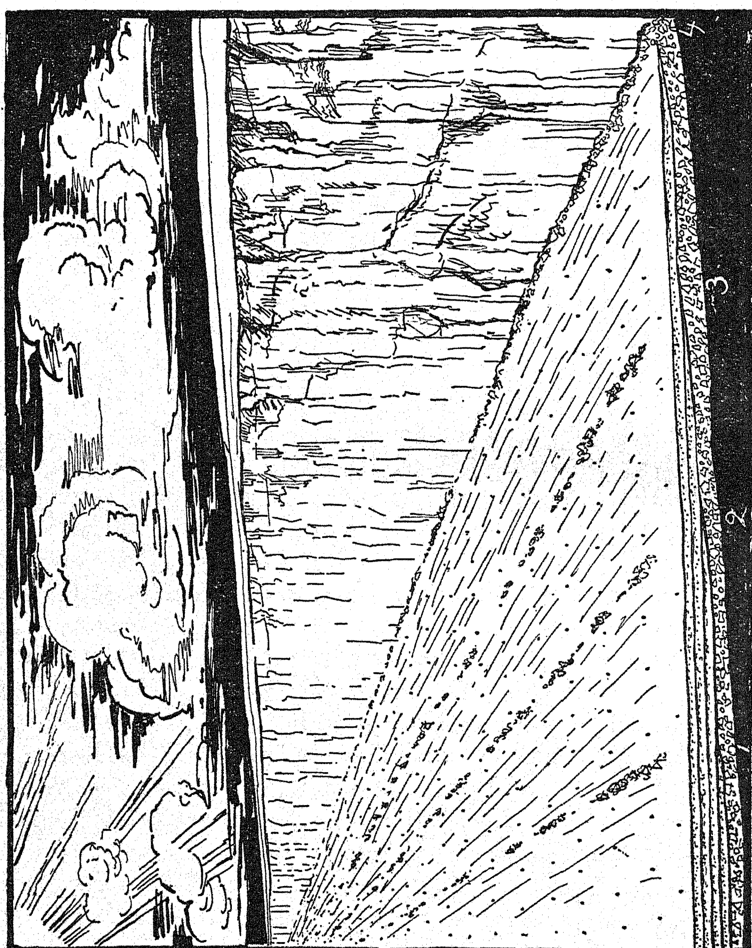


FIGURE 1.—Clay registration of ice recession

such a continuous varve series for the whole of the post-glacial epoch. By the dating of the lowest varves the recession of the ice in Sweden has been determined in detail at more than 1,500 points, while elsewhere, excepting in Finland and in Canada between Ontario and Quebec, sections have rarely been worked out to the lowest varve. Thus, along the Connecticut Valley, according to Antevs' exceedingly interesting and comprehensive measurements, the lowest

of the clay layers was so seldom exposed, that the particular stages of ice recession could be determined only at six points on the whole line. Though it is thus impossible to compute the exact rate of ice recession in this region, his numerous measurements of long varve series have afforded valuable material for detailed comparison with the time scale in Sweden, and for satisfactory verification of the thickness variation of the varves in some otherwise unverified parts of the Swedish scale.

Since the initiative, organization, and method of this investigation are of Swedish origin, and it is apparently only in Sweden that the time scale can be continued right up to the present day, it seems fair to name this standard line of chronology "the Swedish time scale," even where it is verified and completed by parallel measurements in other countries. The main purpose of an exact international chronology must be the reference of different kinds of events everywhere, to one and the same standard of time. The necessary condition for the introduction of such a time scale was, of course, the possibility of identifying synchronous varve variations even at great distances. This condition seems now to be realized. Thus almost all the varve series measured in 1920 by the Swedish expedition to North America have, with certainty, been identified with corresponding series in the time scale in Sweden. This was illustrated by examples representing a few thousand years published (in English) in the Geografiska Annaler, Stockholm, 1926. I have also quite recently succeeded in identifying a series of nearly 600 varves, carefully measured in Argentina by one of my former pupils, Dr. Carl Caldenius. In the same journal was published a description of E. Norin's varve measurements in the northwestern Himalayas, carried out and identified by him in 1925 and 1926, and also late glacial clay varves in Iceland measured in 1919 by H. Wadell and recently correlated with the Swedish time scale by Ebba Hult De Geer. A continuous series of eight hundred varves measured by Dr. Caldenius in southern Chile has also been dated by myself and will soon be published by the Geological Survey of Argentina. Among other correlations performed, here it may only be mentioned that the Swedish time scale has now become extended to the very limit of the Gotiglacial ice oscillation or to the beginning of the corresponding subepoch, giving not quite 8,000 years before the end of the Ice Age and thus considerably less than the 9,500 which were earlier tentatively suggested.

Considering that the distances from Sweden and to these other regions range from 6,000 to 14,000 kilometers, the similarity of more than 80 per cent of the whole identified varve series is very striking. It is especially noteworthy that this similarity continues for century

after century, thus putting it beyond reasonable doubt that only a real identity can explain so considerable a number of similarities.

A close study of the diagrams already published will soon show that the possibility of mere accident must be ruled out. This remarkable coincidence in such rapid variations at such considerable distances, caused by simultaneous melting of ice, seems not to be explicable in any other way than as being due to variations in the amount of heat received from the sun. Thus we have to do with nothing less than a gigantic self-registering thermograph, showing the variations in the radiation from the sun. With respect to the physics of the sun, it is of interest to note that there often exists an observed biennial variation as well as the annual one, which is indicated by the connection of the varve variation of the two hemispheres so that the north and south summers with their closely corresponding varves point to a natural thermal year. It is still unde-

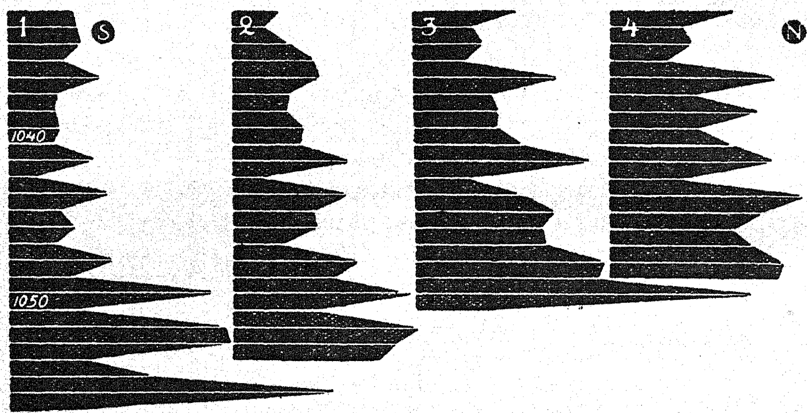


FIGURE 2.—Diagrams for fixing the ice recession

termined in which hemisphere that year begins. For the solution of this question it is of interest that for some years past, observations have been made in Chile, on the solar radiation, for comparison with those executed since 20 years ago on the sunny heights in the far west of the United States.[2] Whatever may be the astronomic cause of the annual solar variation, it seems likely that its beginning and end are probably to be found somewhere between the northern and southern summers, or not far from the equinoxes. When this has been fully established, our annual mean temperature ought to be calculated for the natural thermal year, which should give much more characteristic results than those obtained from the basis of the arbitrary calendar year. Nevertheless, though it be granted that

[2] The measurements here referred to by the author are those carried on by the Smithsonian Astrophysical Observatory at Mount Wilson, Calif., and near Calama, Chile, which have been described in Smithsonian reports for many years.

varve variation in its general features is a function of solar radiation, it is at the same time more or less influenced by local factors

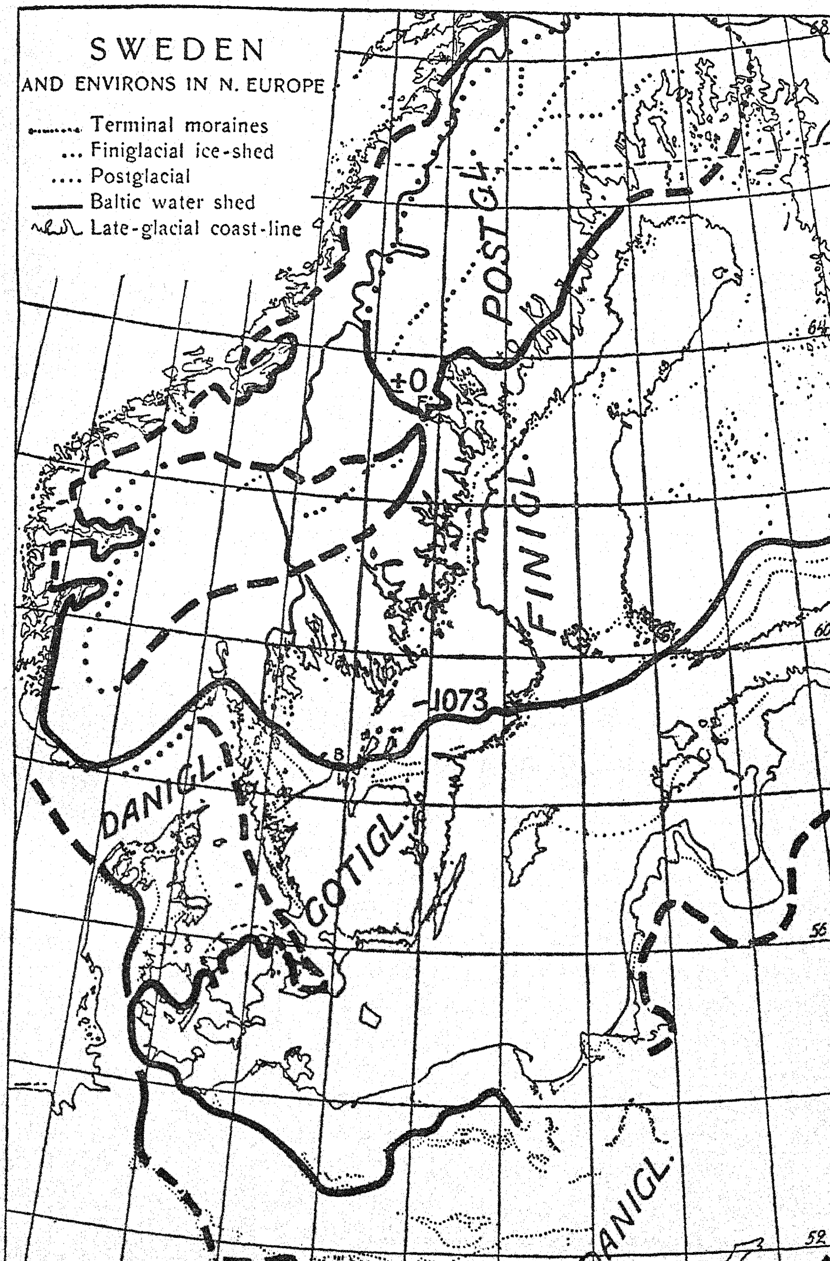


FIGURE 3.—Swedish ice-recession epochs as basis for international chronology

such as the topography of the ground on which the deposit is made, changes in the direction of the melting rivers, the varying composi-

tion of the morainic material from which the clay is washed out, and other circumstances. By parallel measurements in different localities, many such deviations from the true solar curve will probably be eliminated, but meanwhile it is not advisable to transcribe the thickness of the varves into figures intended for exact calculations. Already, however, a really convincing graphic correspondence makes it possible for the first time to introduce the time factor into a great number of geophysical investigations which were hitherto beyond our reach. Thus, to mention a few examples, the possibility of mapping and dating synchronous land-ice borders over great areas in different regions of the earth renders it possible, in connection with the physics of land ice, to make a rational study of the movement and extension of ice, and of its recession as a function of melting as well as of fracturing. In the papers quoted some hints are given concerning the use of time determination for a closer geophysical study of other processes, such as the evolution of climate, and the erosion along rivers as well as along the shores of lakes and seas. Special mention is made of the magnificent example of the Niagara Canyon, the age of which has now been geochronologically dated by means of good varve connections. Thanks to the excellent measurements of American and Canadian geologists we have here a first-class example of the amount of river erosion under certain conditions during a determined space of time. There is only room here to mention fresh possibilities of studying the way in which the recession of the ice was followed by the formation of soil and vegetable mold, and the immigration of flora and fauna into the former great ice deserts.

ARCHEO-CHRONOLOGY

In the autumn of 1924 I had the welcome opportunity of starting, under the auspices of the university,[3] a geochronological institute for the preservation, elaboration, and extension of material in connection with the Swedish time scale and its international use. Up to the present time 12 preliminary papers have been issued from the institute and published in various Swedish scientific journals under the common title of Data. The first of these, Data I, was published in Swedish and was entitled "Förhistoriska tidsbestämningar," or prehistoric datings. It may be well to summarize here some of the views expressed as exemplifying the archeological use of the new time scale.

The period of man is a late conception in the history of the earth, for the first reliable traces of beings who can be considered deserving of the name of man can hardly be found in deposits earlier than the Quaternary period. These deposits form the comparatively thin soil which covers the older formations with their remarkable re-

[3] Of Stockholm.

mains of plants and animals, which more or less differ from any existing species. Naturally enough these earlier layers formerly attracted the most attention, and the Quaternary deposits were looked on mainly as a hindrance to the study of the older formations. Geologically speaking, the Quaternary period was a very short one, and the corresponding geological deposits are, in many places, inconsiderable and uninstructive. Moreover, they vary considerably from one region to another, both in thickness and material, and no general classification of subdivisions has hitherto been possible. Now, however, there are special opportunities of gradually establishing a real time scale for the Quaternary period.

It would seem that the remarkable deterioration of the climate, which caused the glaciation of the Quaternary period and can now be shown to have affected the whole of the earth simultaneously, must have had a great influence upon the ancestral forms of man, and especially so in the regions where it was most severe. This influence may indeed have been the immediate cause of that adaptation to more and more exigent natural conditions and the consequent evolution of intelligence which led to the beginning of the human stage. This was especially true of regions where the supply of edible fruits became insufficient and fishing and hunting became necessary. This led to the development of skill and weapons, while the rigors of climate necessitated the use of clothing and sheltered dwellings. One invention led to another, such as the making of boats, the art of pottery, and that important step in human evolution when man took fire into his service. By extensive excavations in many regions archeology has now been able to establish the succession in which the various types of tools and weapons follow each other, and also which species of animals and plants have been observed together with these finds. In this way, for certain regions, it has been possible to establish so regular a succession of strata as may well justify attempts at correlation within limited areas. With regard to finds from more widely separated regions, however, the risk of error is naturally growing. Primitive types of tools, for instance, are known to have originated independently in different places and epochs and may likewise have been used for varying lengths of time in different regions. Thus, to take a well-known example, certain tribes have existed up to the present day with no knowledge of metals, and are still to all intents living in a kind of Stone Age.

Attempts have often been made to establish the sequence of those climatic changes which seem to be indicated by the organic remains found in various archeological strata. At many places, however, the sequence of strata is very incomplete and, as the Quaternary period shows several considerable climatic variations, it is often difficult to

decide to which of these isolated prehistoric finds should be attributed. Most Quaternary geologists, however, seem to agree that at least two separate glaciations must be regarded as well established, those known respectively as the "great" and the "last glaciation." Of these the last is incomparably the best known, since it is the only one of which the deposits are accessible for close investigation. The deposits of the great glaciation are nowadays preserved almost nowhere but outside the limits of the last glaciation. Deposits from the older stages of the glaciations are often concealed or totally destroyed by the later movements of the land ice. It is not, therefore, surprising that geologists hold very different views with respect to the number as well as the extent of the oscillations of the ice, and also to the question of how many of these may be ranked as independent glaciations. The difficulties in the way of solving this important question are very great, but until they are overcome it is too early to attempt to relate the older cultural epochs of the Paleolithic Age with the glacial or interglacial stages.

The last receding land ice has, however, left to posterity a remarkable and complete autoregistration, covering the whole of the melting epoch. There is here no question of relative computation, but the direct reading and counting of the varves deposited by the water formed every year, as long as the melting epoch lasted. For the late Quaternary epoch, after the maximum of the last glaciation, we have already a very comprehensive series of measurements from a great number of localities, and when the whole has been worked through we shall have an exact time scale for the period which is by far the most important in the evolution of prehistoric cultures. The next stage is to find some region where sediment accumulated during the whole of the Quaternary epoch, in its glacial as well as post- and interglacial stages. These conditions may be found to prevail in several delta regions which received sediment from some greater glaciated area throughout the Quaternary period. Such was the relation of the Ganges-Brahmaputra delta to the eastern Himalaya. It would, however, be impracticable to begin with so immense an area before the method had been tried on a smaller one. The Indus delta would, from every point of view, be more suitable. This delta has recorded the sedimentary deposits from the Kashmir area of the northwestern Himalaya, where, in connection with the Geochronological Institute, E. Norin has begun to make a comprehensive analysis of the Quaternary deposits, which already seems to give a direct correlation with the Swedish time scale. It might, however, prove still more convenient in the first instance to take up the investigation of a delta more easy of access, such as that of the Po, which might be expected to offer a fairly complete registration of Quaternary deposits from the whole southern slope of the Alps.

In order to connect archeological finds with the time scale, several different phenomena can be used. Thus, the situation of the ice border at different stages of its recession can be dated and mapped, whereby it is possible to date cultural remains as well as traces of animals and plants, which immediately followed in the track of the retreating ice. This can probably be done in the case of the Quaternary ice-dammed Lake Pulawy, which was discovered by N. Krichtafowitch, southwest of Warsaw, between the Vistula and the Bug. This lake reached as far as the limits of the last glaciation and its sediments, showing no varves, are covered by the last moraine and contain remains of plants and animals, including *Elephas primigenius*, *Rhinoceros tichorhinus*, *Bos priscus*, *Equus caballus fossilis*, and *Sus scrofa fossilis*; also pieces of bone, and flint tools which were referred by S. Krukowski to the Solutrean epoch.

It is obvious, however, that all attempted coordinations founded only on the occurrence of certain organisms must be merely approximate. Amongst the more reliable geophysical phenomena a first place will doubtless be occupied by such ancient shore lines as can be dated with some accuracy and are adapted for the dating of prehistoric remains, especially those pertaining to shore dwellings. It is true that positions of the edge of the retreating ice can be dated with still greater accuracy, but, in the central parts of northern Europe at least, human occupation had not begun at that time. During the last few years it has been found possible, by a new method of investigation, to follow step by step, and fix by levelling, the present height of a series of unevenly uplifted shore lines dating from the nordic Bronze and Stone Ages. These measurements, which I started some years ago in the Stockholm-region, now embrace the greater part of the Neolithic marine area within the eastern-central parts of Sweden from Ostrogotia to the south of Helsingland. In this way very reliable and detailed knowledge can be obtained concerning the withdrawal of the coast line and the growth of the emerging land. It has also been found possible to connect the different stages of coastal evolution with the Swedish time-scale, and so to date approximately all the phenomena which can be connected with such coast lines.

The question of eustatic shore lines seems to be more complicated and has not been brought into any connection with geochronology.

On the whole it seems desirable that relative as well as approximate time computations should be expressed in another way than real datings and without figures, which give a misleading impression of precision and certainty.

BIBLIOGRAPHY

1888–90. Gerard De Geer.—Om Skandinaviens nivåförändringar under qvartärperioden. [On the Quaternary Changes of Level in Scandinavia]. Geol. Fören. Förhandl. x (1888), 366–79, pl. 2, and ibid. xii (1890), 61–110. [In Swedish.]

1908. ——— On late Quaternary Time and Climate. Geol. Fören. Förhandl. xxx (1908), 459–64.

1910. ——— A Thermographical Record of the Late Quaternary Climate. Die Veränderungen des Klimas seit dem Maximum der letzten Eiszeit. (Stockholm, xi Geol. Congr., 1910.) Pp. 303–10.

1912. ——— A Geochronology of the Last 12,000 Years. Compte rendu de la 11: e sess. du Congrès géol. intern. (Stockholm, 1910), fasc. 1. 1912, pp. 241–57, pls. 1–2.

1921. ——— Correlation of Late Glacial Clay Varves in North America with the Swedish Time Scale. Geol. Fören. Förhandl. xliii (1921), 70–73.

1922. Ernst Antevs.—The Recession of the Last Ice Sheet in New England. Amer. Geogr. Soc., research ser. no. 11, 1922.

1925. ——— Retreat of the Last Ice Sheet in Eastern Canada. Can. Geol. Survey, mem. 146, Ottawa, 1925.

1925. Gerard De Geer.—Förhistoriska tidsbestämningar. [Prehistorical Datings.] Ymer, 1925, pp. 1–3—Data, 1. [In Swedish.]

1925. Erik Norin.—Preliminary Notes on the Late Quaternary Glaciation of the Northwestern Himalaya. Geogr. Ann. 1925, pp. 165–94, pls. 4, 5.—Data 2.

1926. Gerard De Geer.—Om New York-Moränens verkliga ålder och betydelse. Geol. Fören. Förhandl. xlviii (1926), pp. 143–48.—Data, 7. [In Swedish.]

1926. ——— On the Solar Curve as dating the Ice Age, the New York Moraine and Niagara Falls Through the Swedish Time Scale. Geogr. Ann. 1926, pp. 253–84, pls. 1–3.—Data, 9.

1927. ——— Late Glacial Clay Varves in Argentina, Measured by Dr. Carl Caldenius, Dated and Connected with the Swedish Time Scale. Geogr. Ann. 1927, pp. 1–8, pl. 1.—Data, 10.

1927. Erik Norin.—Late Glacial Clay Varves in Himalaya Connected with the Swedish Time Scale. Geogr. Ann. 1927, pp. 157–61, pl. 2.—Data, 11.

1928. Ebba Hult De Geer.—Late Glacial Clay Varves in Iceland Measured by H. Wadell, Dated and Connected with the Swedish Time Scale. Geogr. Ann. 1928, pp. 205–14, pl. 4–5.—Data, 12.

THE PHYSIOLOGY OF THE DUCTLESS GLANDS [1]

By N. B. Taylor
Department of Physiology, University of Toronto

[With six plates]

Thirty years or so ago the study of the ductless glands was a field of practically virgin soil. If we should look into a textbook of physiology of that day, we would find the subject disposed of in a very few words. Since then much has been learned and the work that has been done on these hitherto little-known glands is enormous. Each year literally millions of hours of laboratory and clinical work are performed and thousands of papers are written upon the subject. Unfortunately the great bulk of this work is quite barren of any real or lasting value, for just as a ton of rock must be mined and milled in order to secure an ounce of gold, or several tons of pitchblende be treated to obtain a gram or two of radium, so an immense amount of work must be done by the laboratory mills in order to recover a few grains of truth. We read, from time to time, in the daily papers, in semiscientific publications, and in the advertising literature of some of the drug houses sensational and glowing accounts of the activities of these glands. But most of these glittering tales are misleading and arise from nothing more genuine than a very vivid imagination.

The qualifying or negative word "ductless" implies that these glands are peculiar and distinctive in being without ducts. It implies also that they were discovered later than the more usual type of gland with ducts. It suggests something new and out of the ordinary.

A word first with regard to the usual type of gland. These have been familiar to anatomists and physiologists for hundreds of years. Each is composed of a mass of cells arranged in one or other definite pattern so as to form myriads of tiny spherical cavities. On the outside of the wall of each cavity are blood vessels so that one side of each cell is practically in contact with the blood. From the blood flowing past their doors the cells take what chemical materials they require and with these raw materials manufacture in some mysterious way a very complex substance which they pour into the bowl-like cavities. This material, the gland's secretion, passes into fine hairlike tubes which lead, one from each of the numberless cavities. These

[1] Reprinted by permission from The Scientific Monthly, Vol. XXVII, No. 5, November, 1928. The illustrations here reproduced did not appear in the Scientific Monthly article.

fine tubes are the ducts. They join with one another and form larger ducts. These in turn join to form larger ones, until finally the secretion finds its way into one or two large tubes which open into one of the body cavities, the mouth or intestine, for instance. The arrangement of the ducts is like the stem system of a bunch of grapes—the hollow masses of cells representing the grapes.

Some, such as the tear glands, the sweat or mammary glands, empty upon the surface of the body. Since the activities of many of these glands are associated with experiences of every-day life—crying, sweating, salivation, etc.—it is not surprising that they should have been known for so long. They are characterized by two main features. Their secretions are collected by ducts, and through these they are poured either into one of the body cavities or upon the surface of the body. In short, they are glands of external secretion.

The ductless glands pour their secretions directly into the blood stream. None of their secretions pass outside of the body. They are on this account also called the glands of internal secretion, endocrine glands, or simply the endocrines. Their secretions are also known as hormones. The cells of these glands take in their raw materials by the front door, the arteries, and after fabricating a most powerful chemical material turn the finished product out at the back door, the veins. Thence the hormone is purveyed to all parts of the body.

These glands are little chemical factories of a marvelous ingenuity; and what apparently miraculous effects their concoctions can bring about! Nothing more wonderful was ever dreamed of by the ancient alchemists with their elixirs and potions. It is the action of one of these secretions that paints the plumage of the male bird in such brilliant colors and also prompts its song. Others cause the growth of bone and direct the development of stature along normal lines—overactivity of this or underactivity of that, and a giant or a dwarf is made. Others influence various psychic processes—instinct, emotions, and intelligence. In order that mind and body shall be healthy and normal, all the glands must pour their secretions into the blood stream in proper and due proportions; none must be a sluggard, nor yet overzealous in performing its duties.

Some of the glands are of such a size and prominence that they could not escape the notice of the ancient philosophers. Their uses were pondered and speculated upon, and many fanciful conjectures were made to account for their presence in the body. But their true functions were undreamed of; they were beyond even the imagination of those days.

Before the discovery of their true functions the control of the various parts of the body was believed to be vested entirely in the

nervous system. It was the master tissue. It was the headquarters staff which issued its orders to the various organs, and its authority was believed to be supreme. With the discovery of the ductless glands, an entirely new type of control of the bodily function was brought to light. Their influence, if less evident than that of the nervous system, is nevertheless just as important in their own particular sphere.

The internal secretions have authority over slowly moving processes, such as the development of particular organs, the growth of the body as a whole, and the metabolism of food materials—processes measured by hours, months, or years; whereas the nervous system presides over those rapid processes of thought—muscular movement and the external secretion of glands—processes measured by fractions of seconds (or minutes).

There are many sides from which the functions of the ductless glands may be viewed. I might, for instance, discuss them in their relation to character or to personality or heredity, or even to morality or criminality! And there is little doubt but that they have an influence upon some or all of these, but so far science has been unable to place a finger upon anything very definite. Or I might discuss them in their relation to our "decline into the vale of years," as the poet with such a pleasant euphemism refers to old age. But this side of the question, which has received a great deal of attention in France and on the Continent, is so befogged by pseudoscience and beset with quackery that I would rather leave it alone. I prefer to take up more definite and known effects, effects that can be proved by direct observation or experiment, and to avoid the more speculative side of the subject, which, after all, is no stranger than the truth.

Several methods have been and are still made use of to unravel the mysteries of the endocrine glands. In the first place, extracts of the gland tissue may be prepared which may then be injected into animals and a study made of their effects. Secondly, particular glands may be removed from animals and the subsequent life history of these animals watched, taking careful notice of their subsequent development, growth, or any unusual symptom. Or, thirdly, we may study diseases in the human subject in whom a particular gland is known to be deficient or overactive.

I shall consider first a gland with which everyone to some extent is familiar. This is the thyroid, which lies beneath the muscles of the neck embracing the larynx. When enlarged inordinately, it constitutes the condition known as goiter. All the methods of investigation which I have mentioned were used in the study of the thyroid before any clear idea of its functions was formed.

A certain slight enlargement of the thyroid above the average is an adjunct to feminine beauty. Indeed, one of the older anatomists

thought that therein lay its premier function. It gives a pleasing fullness, a roundness to the contours of the neck, no doubt. This fact was not lost sight of by many of the old masters, who carried the idea to extremes and painted their maidens with necks which verged upon the goitrous.

The thyroid's greatest power for beauty, however, lies not in its size or its shape, but in its secretion. Everyone who has ever seen one of those unfortunates who, from birth or shortly after, had been deprived of his thyroid secretion will know what I mean.

In Switzerland, in the valleys of the Alps, there was to be seen a type of dwarf known as a cretin. A cretin is the direct result of the absence or extreme deficiency of the thyroid hormone. These individuals were truly the most pitiable and grotesque parodies on mankind. They were stunted and deformed in stature and mentally defective or quite imbecilic. Their features were misshapen and flabby. The brow was low, the bridge of the nose depressed, and the nostrils wide; the tongue appeared too large for the mouth, which was coarsely molded. The skin was thick and the hair dry and sparse. I think the description of Caliban must have been inspired by the poet having at one time seen a cretin. Cretins never grew up, but remained for the rest of their lives children in mind and body. Yet had they been Peter Pans—attractive, happy, and intelligent children—all might have been well. But no; they dragged their uncouth bodies through a drab existence, a burden to themselves and their families, or a charge upon the community. The word "cretin" is simply a corruption of the French for "Christian"—chrétien—used in the same sense as the English words "innocent" or "simple" are applied to the feeble-minded.

Though cretins were more common in Switzerland than in other parts of Europe, they were by no means confined to that country. Osler, "within a few years," as he says, was able to collect the histories of 58 cases in Canada and the United States. Cretinism was at one time not uncommon in England, especially in Derbyshire. But it was in the valleys of the Alps, of the Pyrenees, in the Tyrol, and in the Himalayas that it was seen most frequently.

It was not until the gland was removed in young animals that a clue to the cause of the condition was uncovered. Sir Victor Horsley, the famous London surgeon, performed this operation upon monkeys and showed that the symptoms which followed were practically identical with human cretinism. Through this work the responsibility for the cretin was definitely fastened upon the thyroid. This was the gland at fault.

The questions had still to be answered: "Why is cretinism common in certain regions and practically unknown in others?" "Why does the gland fail to perform its proper functions?" The most gen-

erally accepted answer to these questions was that the drinking water was at fault. Even as late as 1910 Sir Hector Mackenzie, a pioneer in this field, wrote, "the most potent cause is the water used for drinking purposes." He admitted that the particular something in the water which affected the thyroid in this way was unknown. Later, however, it was thought to be an infecting organism. (McCarrison.)

Without going further into detail I may say that the question has at last been settled. It is not due to something in the water that should not be there but to something that is not there which should be there, if I may so express it. It is due to a dearth of iodine in water and food. For this knowledge we are indebted to Marine, of Cleveland, who showed a few years ago that thyroid disease in brook trout could be cured by the addition of minute amounts of iodine to the water in which they swam.

That explains why cretins are practically never seen on the seacoast. The sea is an inexhaustible storehouse for iodine, which finds its way into the food and the drinking water of the coast's inhabitants. It is always in inland territories that thyroid deficiency is seen, particularly in the mountains and the highlands, since they, as a rule, are farther removed from the iodine supplies. Analyses of the soils of goitrous districts have shown a marked scarcity of iodine. Chatin, a Swiss, pointed this out 75 years ago, but no attention was paid to the observation.

The thyroid must have iodine in order to manufacture its secretion. Without this element it struggles on as best it can, but it can not make bricks without straw. It becomes enlarged, yet the enlargement is made up, to a large extent, of worthless tissue with its spaces filled with an impotent fluid. The important glandular tissue has degenerated, and though the gland is of greater bulk it is a fraud and is quite incapable of manufacturing an active secretion. We would also find that such a gland was almost barren of iodine, or at any rate held but a fraction of the normal amount. It is now an axiom of thyroid pathology that the larger the gland the less is the iodine which it contains.

This is the usual way in which cretinism occurs, following goiter, which destroys the functional activity of the gland. But in rare instances thyroid function may be destroyed by some acute disease of childhood, or rarer still, some unlucky individual may be born without one.

A similar condition, and one having the same cause, may arise in adult life. It is known as myxedema and is essentially the same as cretinism. There can, of course, be no stunting of the stature or maldevelopment of the bones, since it appears after the period of

growth. Myxedema was common in the same regions where cretins were found.

In my discussion of cretinism and myxedema I have deliberately kept to the past tense, for the very good reason that they are practically things of the past. Medical science in its progress has swept them from its path. We might travel through the Alps to-day and I do not think that we should see a single cretin unless it was a case of long standing.

Cretins and myxedematous subjects owe their changed fortunes to an English physician, Dr. George Murray, now emeritus professor of medicine at Manchester. It occurred to this investigator to extract the thyroid glands of sheep with glycerine and to inject this into the subjects of thyroid deficiency. It is interesting to recall how this idea first came to Murray. He read of an operation performed by two foreign surgeons, Bettencourt and Serrano, in which they had acted upon the suggestion of Sir Victor Horsley and grafted a portion of a sheep's thyroid beneath the skin of a victim of thyroid deficiency. They reported an improvement in the condition. Murray says, "this observation indicated to me that the gland carried on its functions by means of an internal secretion." He therefore concluded that it might be possible to extract this secretion from the glands of animals and that it might serve as a suitable substitute for the secretion that was lacking. In 1891 he reported the results of his first trials with the extract.

Of all the discoveries in the field of medicine this was one of the most brilliant. The extract fulfilled the hopes of even the most sanguine. Its success was complete. It was able within a remarkably short time to conquer all the symptoms of thyroid deficiency in the adult, that is, myxedema.

His success with the cretin depended upon how long the condition had existed before treatment had been commenced. Obviously not such great benefits could be expected in a case which had existed for years where brain, bone, and muscle had been confirmed in their abnormal state. Yet even in these the improvement was often very striking. But in the early cases the effects appeared to be little short of miraculous. No potion brewed in magic caldron ever produced a greater change than did Murray's extract. As though enchanted, the stunted and gnomelike body of the cretin grew to normal proportions. The ugly mask fell from the face, and the limbs took on the human grace which nature had hitherto denied them. But, greatest benefit of all, the light of reason returned to the clouded mind and in a short time these apparently hopeless imbeciles were turned into happy and intelligent children. It is no longer necessary to inject the extract, for it can now be taken in tablets. To-day there should be no cretins under 40 years of age. If one younger than this should

be seen, he is a sad reproach to some one, whether physician or parent, who has failed to bring to this blighted one the certain cure which is ready at hand.

There is another reason why cretins are rare to-day, and that is the occurrence of goiter is prevented. The cause is removed. Iodine is added to the drinking water or the food, or given in small doses a few times a year to the children of the Swiss cantons and other regions where goiter is prevalent.

There is little doubt, then, of one function of the thyroid gland. It controls the growth and the development of both body and mind. It takes iodine and other materials from the blood and manufactures a secretion or hormone which produces these effects.

In order to bring further conviction, I shall cite a very interesting experiment that was carried out a few years ago upon tadpoles, ordinary polliwogs, whose destiny is, as you know, to grow into frogs.

A group of tadpoles which had been hatched from the same batch of eggs a short time previously was placed in a small aquarium. A number of these creatures were operated upon and their thyroids removed—rather small subjects, you might think, for a major operation, and rather poor risks, too. But a certain proportion of them made a good recovery and continued to swim about after their convalescence, just like a number of their brothers who had been allowed to keep their thyroids.

The animals without thyroids, however, never grew into frogs. The experimenter, with his scalpel, had shaped their destinies. The joys of frogdom were not for them. Never were they to spring from slimy pools to breathe the air or bask in sunshine upon a lily pad. They remained polliwogs for the rest of their lives. They were the counterparts of human cretins in so far as body growth and development went. Since their mentality is scarcely of a measurable quantity, no one can say how they progressed in that direction. They can not be subjected to intelligence tests, nor do we know what their brothers thought of them; so that side of the question must be left to the imagination. Their normal brothers, which were kept under precisely the same conditions, lost their gills and tails, grew arms and legs, and matured into frogs in the usual way and in the usual length of time, two and a half to three months.

If thyroid extract was given to the cretinoid tadpoles—a small quantity merely dropped into the water in which they swam, or fresh thyroid tissue fed to them—they commenced to develop in the usual way and in due time were hopping about, perfectly normal frogs.

On the other hand, when extract was added to the water in which the normal tadpoles lived, those which were not deprived of their thyroids—they developed into frogs ahead of time. Their development was speeded up. The gills and tail disappeared and the limbs

grew out in about a third of the usual time. It can easily be understood why this should be, for their bodies were receiving an excessive amount of thyroid principle, that manufactured by their own thyroids plus that given to them by the experimenter.

Thyroid function has been tested out on another close relative of the frog family. In Mexican waters there is a strange creature known as the axolotl. It is considered quite a delicacy by the Mexicans, though I think that if you ever saw one its gastronomic possibilities would not interest you. The axolotl is a sort of halfway house along the evolutionary path, between a fish and a frog. It looks like a huge tadpole, for it is several inches long, that had started out to be a frog but thought better of it, and remained a grotesque-looking object with gills, a finned tail, square head, and short fore and hind limbs. This is the usual adult form of these creatures; they breed in this form, many of them never developing into land animals and a few others doing so very, very slowly. If they are fed upon beef thyroid—even one or two meals is enough—they develop into air-breathing animals. They lose their gills and tail fin and develop air-breathing organs. The head becomes oval and the eyes prominent.

Here is an instance in which an animal, forsaken, as it were, at a certain wayside station in the evolutionary journey, has been brought a step further by an internal secretion. I promised not to speculate, but I can not help but wonder just how important a part the ductless glands have played in the evolutionary process.

The thyroid has another entirely different duty to perform besides those mentioned before. Its hormone is to the body as a forced draft is to a furnace. It fans the fires of life. You all know that the body shows a very real likeness to a furnace or an internal-combustion engine. Its muscles consume fuel and in doing so use oxygen and give out carbon dioxide, just as any combustion engine does. Energy is liberated, heat is produced, and work is done. Thyroid extract increases the combustion in the muscles. More heat is produced with extract than without. The fire in each cell burns more fiercely. The metabolism, as the physiologists say, is increased.

In those suffering from thyroid lack the fires are dampened down. They glow dully, not brightly as they should; metabolism is lowered. The metabolism may be altered 50 per cent either way by an increase or a decrease in thyroid secretion. On this account very serious effects will result if a normal individual should take thyroid extract for any length of time, for in that case the administered dose added to the natural secretion would increase the combustion within the body to a dangerous degree. Sometimes the thyroid has an exaggerated sense of what is required of it and manufactures more of its

very potent secretion than the body needs. The symptoms of overdosage soon become evident. I shall not dwell upon the details of this condition. There is of course increased metabolism, which requires special methods for its detection. The most evident feature is protruding eyeballs, though it is by no means certain that this symptom can be laid at the thyroid's door. Indeed there is much evidence that it can not.

Ever since Murray showed that the functions of the thyroid were due to an internal secretion and that this could be extracted, many investigators have endeavored to isolate the active principle, or essence, one might say, from the more or less crude extract which he first obtained. As a result it was not long before some knowledge of the chemical nature of the active principle was gained. A few years ago this principle was obtained in pure form by Kendal, of Rochester, Minn. He "dubbed" it thyroxin. It contains iodine, about 60 per cent combined with certain well-known organic materials. The iodine radical is believed to be responsible for the growth-promoting functions of the thyroid, and part of the organic radical (pyrrol) for the effect upon metabolism. For if the iodine portion be broken off, the remainder still increases the metabolic rate, yet it has now lost its influence upon the metamorphosis of tadpoles. On the other hand, if the pyrrol group alone is broken off, the material exerts its usual effect upon the tadpole.

Harrington, in England, within the last couple of years, has actually succeeded in manufacturing this material in the laboratory, that is, in producing it artificially from its chemical constituents. It has all the physiological properties of the natural product. But it, as well as Kendal's thyroxin, is many times more powerful than Murray's crude extract; an almost insignificant amount will produce the most profound effects. It may be looked upon as the quintessence of the thyroid juice, a superextract.

The pituitary is another ductless gland which has just as important duties to perform as the thyroid. But it is only a fraction of the size of the thyroid. In man it is scarcely larger than a cherry and lies like an Atlas at the base of the brain with the huge hemispheres heaped above it. And like Atlas, its responsibilities are great, for if it is removed or destroyed the whole body is thrown into chaos. It is cast into an abyss from which all the gods are powerless to raise it; death follows inevitably and swiftly. As may be seen, this gland is composed of two parts, which, though they are in intimate contract with one another, have entirely different functions to perform. The two divisions are spoken of as lobes, the anterior and the posterior.

The pituitary has been a puzzle since ancient times. It is only within recent years that a glimpse of its true functions has been

allowed us. Since it lay on the floor of the skull not far from the root of the nose, some of the ancient writers thought that it existed for the purpose of secreting mucus into the nostrils—indeed, that was how it got its name; pituita, mucus, and phlegm were cognate terms in the middle ages. Others, with perhaps more poetry in their make-up, thought that it was the throne of the soul.

As I have said already, one of the main avenues of approach to an understanding of the internal secretions has been through a study of their disorders in the human subject. The first step toward our present-day conceptions of pituitary function was made by the French physician, Pierre Marie. It was he who first described a condition characterized by overgrowth of the bones of the face, hands, and feet. The enlargement of the facial bones was seen particularly in the ridges above the eyes, in the nose, and lower jaw. In some cases reported by Marie this member measured 18 inches from ear to ear, and the chin was some 4 inches deep. The soft tissues also were thickened, the combination of fleshy and bony overgrowth producing extreme coarsening of the features. This in many cases amounted to grotesque ugliness. The bones of the hands and feet, especially the former, showed a similar overgrowth. This was no moderate enlargement, for the hand of one of these individuals might be double the size of that of a normal person of the same height.

Marie ascribed this condition to disordered function of the pituitary and called it acromegaly, which any Greek scholar would at once tell us simply meant "big extremities." Marie thought that it was the result of depression of the pituitary function, but we know now that it is due to just the reverse, increased secretion by this gland. The disease comes on more or less gradually, but the changed facial expression is rendered very noticeable if a photograph of the subject, taken perhaps 5 or 10 years previously, be compared with the same person in the flesh.

The disease, if it progresses, is invariably fatal, and in all these cases an enlargement of the anterior part of the pituitary has been found after death. There is no doubt then that it is this part of the pituitary which is at fault.

Sir Arthur Keith, the noted anatomist and anthropologist, has thrown an interesting side light on this condition. While classifying a collection of skulls in the museum of the Royal College of Surgeons in London, he came across one that was undoubtedly acromegalic. He at once recognized the prominence of the bone above the eye sockets, the massiveness and elongation of the lower jaw, and the general enlargement of the face area of this skull. The other stigmata of acromegaly were unmistakable. But what struck him most was the remarkable resemblance which this skull bore to the skull of Neanderthal man—one of the earlier of the prehistoric

men in Europe. By careful measurements of the two skulls, the acromegalic modern and the normal prehistoric, he found that each showed the same essential characteristics. Upon the skulls of the higher apes are also seen many of the features of the acromegalic skull.

These facts prompt the question: Is the pituitary of man of to-day less active than was that of prehistoric man? In other words, was a secretion which would be considered excessive and pathological to-day normal and physiological to Neanderthal man? We are also tempted to ask whether a gradual lowering of pituitary function has been an aid or an important factor in the evolution of the facial and other skeletal characteristics of modern man. These questions may be asked, but no one, I think, has been bold enough to answer them dogmatically. And there is one great difficulty in considering these suggestions. We shall show in a moment that the growth-promoting power of the pituitary is not confined to the bones of the face and extremities, but extends to all the bones of the body. We would, therefore, expect, if the gland had the effect which Sir Arthur suggests, that the prehistoric man with the beetling brows and the massive jaw would have been a giant. But he was nothing of the sort; he was in fact below the average height of modern man.

Acromegaly is a disorder of the anterior lobe of the pituitary in adult life; that is, after the normal period of growth. But this part of the pituitary may suffer the same disorder in earlier life; that is, during the growing period. The gland may, just as in the case of acromegaly, become too zealous and secrete an inordinate quantity of its very powerful hormone at this time. When it does, it is not only the bones of the face and extremities which overgrow, but all the bones of the body are urged into an extraordinary overdevelopment. In this way are giants made. Those men of tremendous stature who earn their livelihoods in circus side shows are instances of overactive pituitary glands. Some of these giants reach the "altitude" of 8 or 9 feet. They would knock their heads against the ceilings in the modern Toronto house and would need to bend nearly double to pass through a doorway. The tallest which I have seen reported was a Finn, 9 feet 5 inches. But there has been a Chinese giant reported who was 8 feet 1 inch, and an American recorded by Dr. Harvey Cushing as over 8 feet 2 inches. These are the extreme cases, but there are many degrees of giantism or gigantism, as the condition is called. A certain French baron some years ago sought by encouraging the intermarriage of giants and giantesses of this type to produce a race of supermen, but the experiment, for which a million francs was subscribed, proved a dismal failure. The gigantic parents had average-sized offspring. And this is a characteristic

of pituitary giantism. The giants are usually the children of normal parents and they themselves have normal children.

The pituitary by these excesses, acromegaly and gigantism, has revealed itself. There is every reason to believe that its physiological function is to urge the growing bone within normal limits.

If the pituitary can increase its output above the normal and produce giants, the question naturally arises whether it ever fails to manufacture enough of its hormone and produce dwarfs. It does, and there are two kinds of dwarf which may result from a deficient pituitary secretion. Only one of these is caused by deficiency of the anterior lobe alone. He resembles the midget, but differs in certain essential features from that popular attraction of the side shows. The midget remains unexplained; he may be a pituitary case, but there is no evidence that he is. The true anterior lobe dwarf is a rather quaint little person. He (or she) is perfectly proportioned, delicately formed, and usually of a pleasing appearance. To the casual observer he appears normal in every way except in size, and his intelligence is usually of the average grade, though in some cases it is below the normal. They are men and women in miniature—adult figures, seen as it were through the wrong end of the telescope, for their bodies are never proportioned upon the plan of the child, that is, with relatively large heads. Nor are their facial features childlike.

Very frequently the posterior lobe as well as the anterior is deficient. The disorder then is one of the pituitary as a whole. There will be seen a combination, a mixture of effects, some caused by one lobe, some by the other.

Before these combined effects can be described the functions of the posterior lobe must be outlined. The duties of this part of the gland are not so clear as those of the anterior. True, an extract may be obtained from it which produces immediate and very definite effects when injected into an animal. It causes, for instance, a rise in the blood pressure and induces contractions of the muscular walls of various organs of the body. But whether they are part of a true physiological function or merely effects produced through artificial methods of extraction can not be said.

There is no evidence that the posterior lobe is concerned in any way with the development and growth of the bones. There is one function, however, of which there seems to be no doubt. It is concerned with the disposal of sugar by the body. When its secretion is produced in insufficient amount, there is a remarkable increase in the quantity of sugar which the body can use. If a normal person takes a large quantity of sugar, it is not all utilized by the body cells. The excess can be found in the blood and is later excreted. The subject of posterior-lobe deficiency can utilize several times that

which the normal individual can use. It would appear that this excessive utilization can not be accounted for by increased combustion of the sugar and consequently by a greater production of heat, for these subjects have a body temperature that is lower than the normal, and the general metabolism is actually depressed. The excess sugar is evidently used for the formation of fat, since the outstanding feature of these subjects is the great overdevelopment of fatty tissue. Injections of an extract of the posterior lobe produce the opposite effect, a reduction in the body's ability to use sugar.

Pituitary disorders of this nature are not infrequently seen in children. Many children, as we know, have a tendency to increase their fatty tissue at a certain age, and this may be due to a normal variation of the posterior-lobe hormone. But these individuals with posterior-lobe deficiency are not just ordinary fat children. Their fatness is really extraordinary; they are veritable roly-polies and present a striking appearance. They have often a voracious appetite and have, even for children, an inordinate longing for sweets of all kinds. They are, as a rule, somewhat below par mentally, progress slowly at school, and show an unchildlike lethargy—ready to sleep at any time. Dickens's fat boy, I think, must have been a pituitary case; and the little fat boy whom many of you may have seen in the movies, as a member of that humorous group of children known as "the gang," has, I think, if the truth were known, a pituitary whose posterior lobe is not quite doing its duty. Great obesity may result from posterior-lobe deficiency in adults also, and the fat woman of the circus is in many cases, no doubt, an example of this condition. Indeed the vagaries of the pituitary have proved a great source of profit for the circus proprietor.

When there is a deficiency of the anterior lobe accompanying the deficiency of the posterior lobe, there is a combination of the effects characteristic of both parts of the pituitary. Arrested growth, added to the extreme obesity, produces a remarkable type of dwarf. His length and breadth approach equality. Gigantism with obesity will also occur if overactivity of the anterior lobe be associated with deficiency of the posterior.

EXPERIMENTAL

All these instances go to show the direction in which the activities of the pituitary lie. If disorders of its function produce these abnormalities, it is, I think, logical to assume that its physiological function is to influence the growth of the body within normal limits (anterior part) and to furnish a hormone which controls in some way or other the conversion of sugar into fat (posterior part). Until recent years little support for these conclusions, arrived at from

24034—29——46

the study of human cases, could be obtained from animal experimentation. The other two methods of approach, use of extracts and removal of the gland, failed to produce decisive results. Recently, however, Evans and Smith, of the University of California, have been able to show in a truly spectacular fashion the profound effect which the anterior lobe has upon growth. They have been able to prepare an extract of the anterior lobe which has this effect. The experiments were carried out in this way: Pituitary glands (anterior lobe) of the ox were minced and extracted with salty water. The extract obtained in this simple way was then injected into young white rats over a period of several weeks. Other rats of the same litter were kept under precisely the same conditions and received the same food, but were not injected with extract. These untreated rats served as standards or controls, as they are technically called, to which the injected rats could be compared.

The period of growth of the normal laboratory rat is now well known. It is from 150 to 180 days. At the end of this time it has reached the adult form and size and ceases to grow further. The control rats followed this normal course. The treated rats, that is, those injected with the extract, did not cease to grow when the end of this period was reached, but continued to grow for several weeks afterwards. They finally developed into huge, giant rats. Though they were not, perhaps, as large as the rats that Gulliver adventured with in Brobdingnag, they were at least 60 per cent, and in some cases 100 per cent, larger than their brothers and sisters of the same litter which had received no extract.

The other side of the picture was also outlined by experiment; that is to say, depression of the pituitary function produced the reverse effects, retarded growth. On account of the small size of the pituitary in the rat it is impossible to destroy one part of the gland without injuring or destroying more or less of the other part as well. There is also the danger of damaging too severely the anterior lobe, which is essential to life. It was therefore impossible to produce pure effects of one or the other lobe. The effects were what might have been expected from partial destruction and consequent deficiency of both lobes. The animals became very fat and failed to grow to normal size. They corresponded very closely to the type of dwarfs already described for human subjects as a result of deficiency of both lobes. These animals, however, usually showed the obesity more than the dwarfing; they were so rotund that they resembled nothing so much as little balls of cotton wool.

Before leaving the subject of the pituitary I must speak of another strange effect which its secretion has upon certain members of the amphibian and reptile families. Many of you no doubt have been fascinated by the way in which some of these creatures, such as the

tree toad and certain varieties of lizard, particularly the chameleon, apparently change the color of their skins to match the background upon which they lie or cling. Many fish also are endowed with this ability. Even the common frog is of a darker tint in subdued light or on a dark background than it is in bright sunshine, where it appears to become "bleached" to a much lighter shade of green or yellow.

The frog's skin, as you know, is not of a solid color, but is marked with dark spots or blotches which overlie a light greenish-yellow ground. This mottling is particularly well marked in one species, the leopard frog. If the dark spots are examined beneath the microscope, they will be found to be made up of groups of cells with many branching arms and containing granules of a dark pigment. These cells expand in the dark or in dim light and contract in bright light. Or, I should say, rather, that the pigment collects near the center of the cell when the light is bright, but streams throughout the whole cell and into its branching arms when the frog is in darkness. So the blotches become larger and take up a greater part of the skin pattern, and less of the underlying green or yellow pigment of the skin shows through. This action of the cells of the frog's skin was a puzzle to biologists for years. They thought that nerves must be concerned in the reaction, yet this could not be demonstrated with general satisfaction. One competent observer, for instance, was convinced that the reactions were carried out through the sense of touch in the skin of the toes, for, he said, when the toes were rendered anesthetic by cocaine the responses did not occur. He thought that the textural qualities, hardness, roughness, etc., of the various materials, such as stone, grass, wood, earth, etc., upon which the animal rested produced color reactions in the pigment cells corresponding to the color of these materials. In other words, the nerves established an association between the texture or any other "touchable" quality of a material and its color. This theory, on the face of it, seemed improbable, and it is not at present entertained.

If a few tadpoles be taken and their pituitaries removed—this can be done quite easily in this creature, for the gland lies in an accessible position beneath the upper surface of the head—very soon we should find that the animals had lost their natural dark color and appeared as mere silvery ghosts of their former selves. This suggests to us at once that the same thing which bleaches the tadpole also bleaches the frog. Does the lack of pituitary secretion cause the pigment granules to retreat to the center of the cells, and does the presence of the hormone in the blood cause them to spread throughout the cell body? We can easily put this suggestion to the test. If a frog be injected with an extract of the posterior lobe, its skin within a moment or two becomes coal black. After removal of the pituitary, on

the other hand, the frog is unable to alter the color scheme of its skin when the illumination of its surroundings is altered. There is little doubt, then, of the action of this portion of the pituitary upon the pigment cells of the frog. If the eyes of a normal frog are covered with some opaque material, the color reaction does not occur.

Now, we can form a picture of the mechanism by which the animals change their tinting according to the light. If the frog is in a bright light or upon a light background, the retina is stimulated by the rays of light. Impulses pass along the optic nerves to the brain, and some of these impulses are sidetracked to the pituitary's posterior lobe and its secretion is suppressed. The suppression persists so long as the rays of light are entering the eyes. The pigment cells, however, do not at once become pale, for the secretion which had been circulating in the blood, and which keeps the cells expanded, must first be used up. This takes a certain time, but as soon as it is complete the cells appear to shrink, and a sickly greenish-yellow pallor creeps over the amphibian skin. In this way does the frog, leopard, or other variety, change his spots; but the Ethiopian can not change his skin, for no corresponding reactions have been shown to occur in man or in any of the higher animals.

Limited space permits me to consider only two ductless glands. I have chosen these two because more is known of them than of others which I have not touched upon. I might, for instance, have discussed the parathyroids, those tiny glands which lie beneath the thyroid. They are essential to health, and indeed to life itself, though even in an ox they are no larger than a bean. They govern the amount of calcium in the blood. If they are removed, the calcium is reduced, and an extract prepared from them when injected into an animal causes the calcium to rise.

Or I might have taken up the adrenal glands, which lie near the kidneys and are believed by some to enhance the reactions of the primitive emotions, hate, fear, anger, etc. There are also those glands which have been shown to exert such influence upon the development of the secondary characteristics of sex, such as the plumage of birds and the antlers of stags. There are also the pineal gland and the thymus, the one lying deep in the brain, the other deep in the chest, and both shrouded in the deepest mystery. There is also the pancreas, which pours insulin into the blood stream, but the study of this hormone is a very large subject in itself.

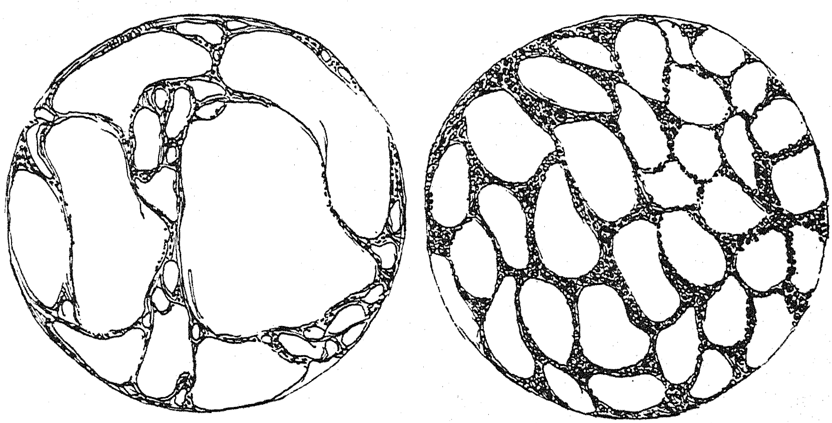
I have treated the glands of which I have spoken as though they were quite independent one of the other. This is unavoidable, because this is the way in which they have been studied, and this is the way in which most of the information regarding them has been gained. Yet there is no doubt that their actions are very closely related one with another and that it is purely artificial to study them

in water-tight compartments. It is, however, at the present time impossible to do otherwise.

We should look upon the secretions of the ductless glands rather, I think, as forming with the blood a suitable environment, an appropriate fluid medium to bathe the cells of the tissues. When all secretions are present in their correct proportions, the cells are healthy, they flourish and grow normally. If, on the other hand, one or other constituent of this nicely balanced mixture be present in reduced or excessive proportion, the environment becomes unsuitable and the cells suffer. Their development along the particular paths which hereditary impulses direct them is thwarted, and abnormalities result.

In order that there shall be physiological harmony, each endocrine gland must play its part in tune with its fellows.

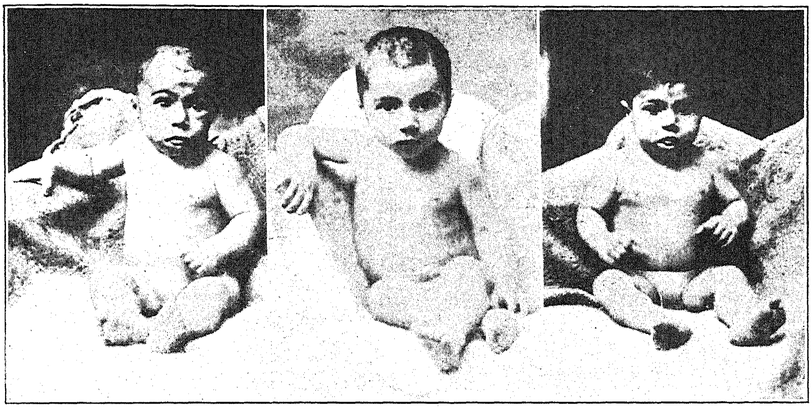
1. CRETIN AGED 10 YEARS
(From McCarrison, after Thomson)



2. MICROSCOPIC SECTION OF THYROID TISSUE IN GOITER (LEFT) AND THE NORMAL STRUCTURE (RIGHT)

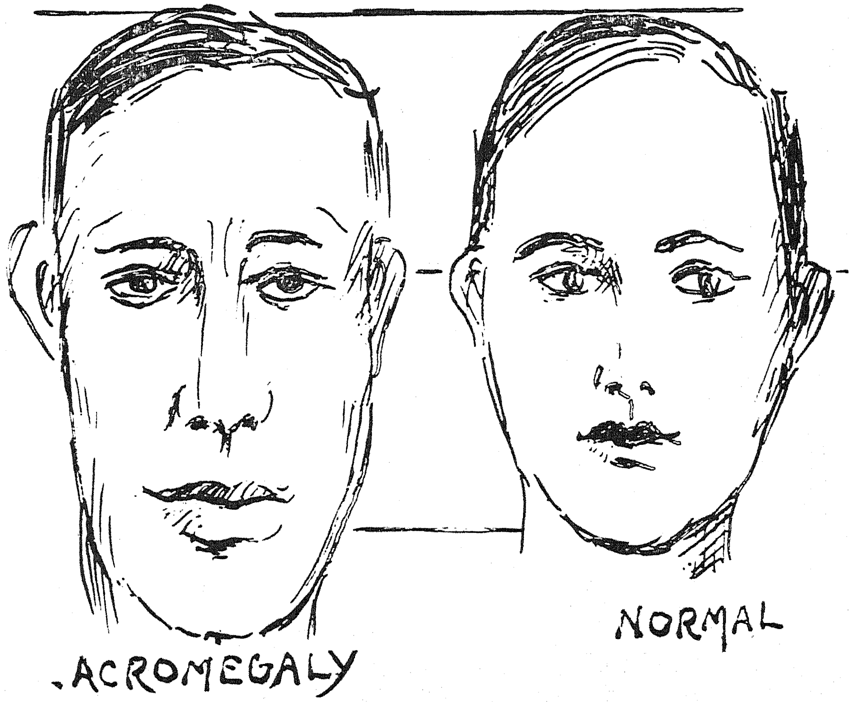
1. MYXODEMA OF 15 YEARS' DURATION

2. SAME AS FIGURE 1, THREE MONTHS AFTER TREATMENT WITH EXTRACT OF THYROID. (MURRAY)

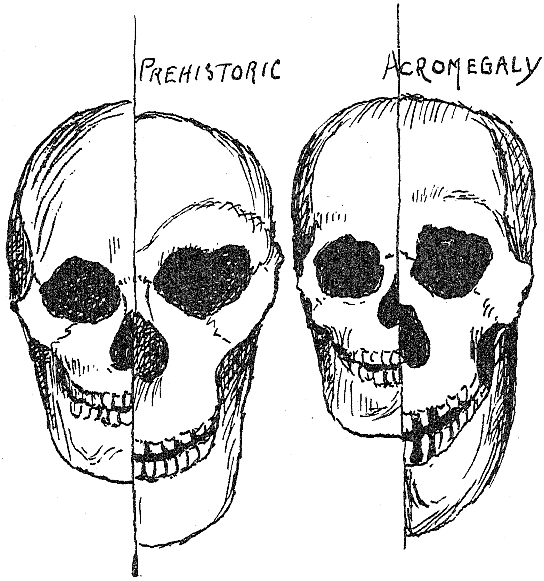


1. EFFECT OF THYROID ADMINISTRATION UPON CRETINISM

Center, after short course of thyroid extract; left and right, same child before treatment. (From J. S. Huxley)

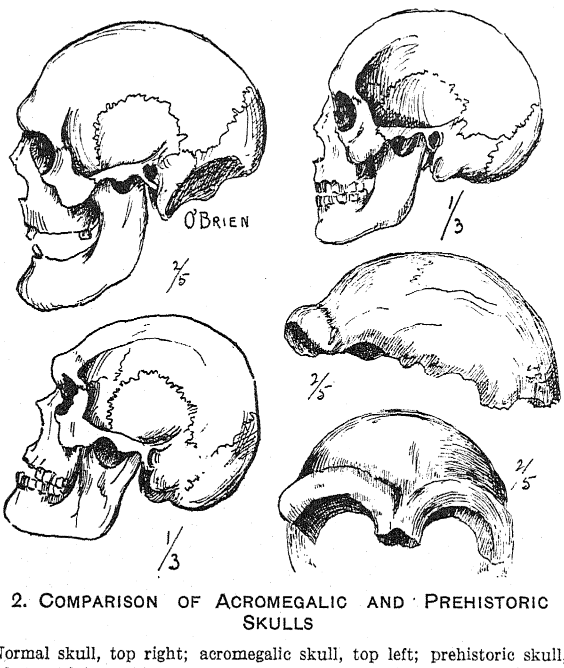


2. SHOWING ELONGATION OF FACE FROM EYES TO CHIN IN ACROMEGALY



1. DIAGRAM TO SHOW ELONGATION OF FACIAL AREA IN SKULL OF PREHISTORIC MAN AND IN ACROMEGALIC SKULL

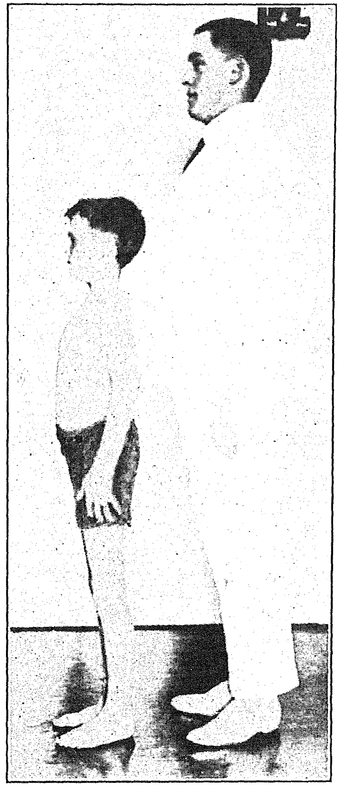
Normal skull on the left of vertical line in each case



2. COMPARISON OF ACROMEGALIC AND PREHISTORIC SKULLS

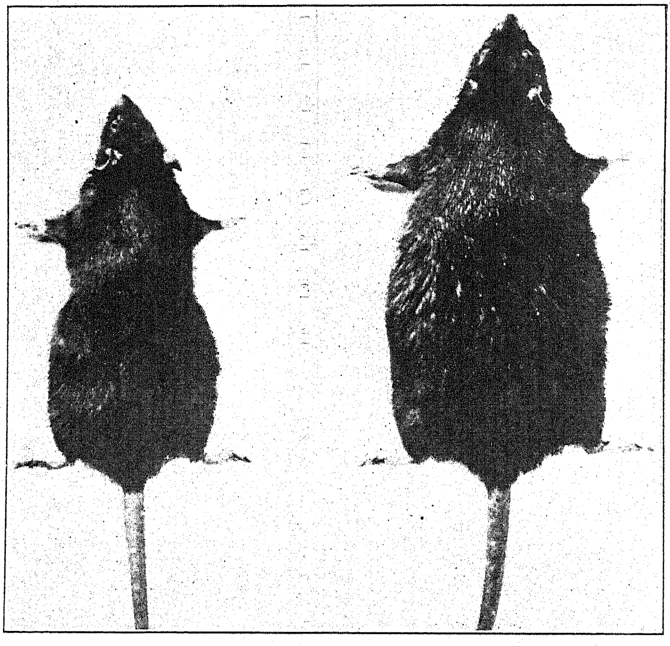
Normal skull, top right; acromegalic skull, top left; prehistoric skull, bottom left; prehistoric skullcap, to show prominence of eye ridges, bottom right

1. DUTCH GIANT, VAN DEUSEN, 8 FEET 9 INCHES. NORMAL WOMAN ON RIGHT, DWARF ON LEFT

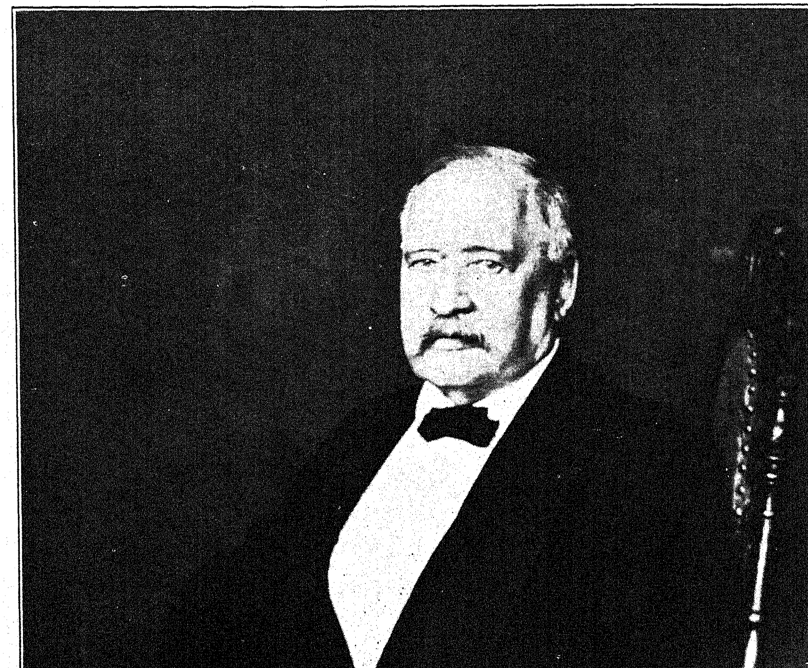


2. INFANTILISM DUE TO ANTERIOR LOBE DEFICIENCY. AGE 21 YEARS. MAN ON RIGHT, 5 FEET 7 INCHES

1. DWARFISM DUE TO DEFICIENCY OF BOTH LOBES OF PITUITARY. (CUSHING)



2. EFFECT OF EXTRACT OF ANTERIOR LOBE OF PITUITARY UPON GROWTH OF RATS. LEFT, CONTROL; RIGHT, TREATED WITH EXTRACT. (EVANS)



SVANTE AUGUST ARRHENIUS (1859-1927)

SVANTE ARRHENIUS[1]

By Sir James Walker

[With one plate]

A little over 40 years ago the conjunction of the ideas of osmotic pressure and of electrolytic dissociation ushered in a new era in the development of the physical chemistry of solutions—an era of unexampled fertility. Van 't Hoff and Arrhenius, the originators of these new ideas, have now both passed away. It is 16 years since I was charged by the society to deliver the van 't Hoff memorial lecture. To-day it is my task to discharge a similar duty in honor of Arrhenius. My relations to these men were altogether different; Arrhenius was a close friend, van 't Hoff a remote immortal. The sketch of the life and work of Arrhenius which I present is therefore not that of a completely detached historian, but is shaped by personal reminiscence and tinged with personal affection.[2]

I well remember when I first encountered his name. It was in the autumn of 1887 in the small departmental library of Baeyer's laboratory in Munich. On a shelf there lay the loose numbers of the first volume of the Zeitschrift für Physikalische Chemie, newly founded by Ostwald. Turning over the pages of this interesting new journal, I saw what seemed to me the very odd name of Svante Arrhenius as author of a paper on the influence of neutral salts on the velocity of saponification of ethyl acetate. I did not find this paper of more than moderate interest, but later in the year there was published another by the same author on the dissociation of substances dissolved in water. This was plainly a novel and striking conception, and although I was not altogether convinced by the arguments it contained I marked it for closer study at a later time.

In the spring of the following year I left Munich for Leipzig and was caught in the wave of Ostwald's enthusiasm for the new doctrines of osmotic pressure and electrolytic dissociation. In Ostwald's laboratory I used to work in a small room with Wilhelm Meyerhoffer,

[1] Arrhenius memorial lecture, delivered on May 10, 1928. Reprinted by permission from the Journal of the Chemical Society, 1928, London.

[2] I take this opportunity of thanking the many friends, both Swedish and English to whom I am indebted for information regarding Arrhenius. A bibliography of his work up to 1908 is to be found in Z. Physikal. Chem., vol. 69, and up to 1918 in Medd. K. Vetenskapsakad. Nobel-institut, vol. 5.

who afterwards collaborated with van 't Hoff in his phase-rule investigations. One day Meyerhoffer burst into the room, and pointing excitedly along the corridor, said, "Arrhenius is there." I peered out and saw a stoutish fair young man talking to Ostwald near the entrance hall. It was Arrhenius. We were made acquainted by Ostwald, but at that time I saw little more of him. Next year he came to work in Leipzig, and I had the opportunity of meeting him daily. He was one of the simplest and least assuming of men. He gave himself no airs and treated us young fellows as if we were his scientific equals, although at that time he was being recognized in Germany as a leading spirit in physical chemistry. In his own country he was still unregarded.

Svante Arrhenius came of Swedish farmer folk, a remote ancestor being one Lasse Olofsson, who in 1620 moved to the village of Årena, from which the family derived its surname in the Latinized form of Arenius, the spelling being changed in the early part of the nineteenth century to Arrhenius by the uncle of Svante, Prof. Johan Arrhenius, a botanist and secretary of the Academy of Agriculture. Johan and his younger brother, Svante Gustav Arrhenius (1813–1888), the father of our Svante, went as students to the University of Upsala, and the latter subsequently established himself in that town as a land surveyor. He was appointed collector to the university, but the emoluments of the post were so meager that he was forced to undertake in addition the management of the estate of Wijk, on Lake Mälar, which belonged to Count von Essen. He married in 1855 Caroline Thunberg, and at Wijk there was born on February 19, 1859, a son whom they called Svante August Arrhenius. Owing to improved prospects the family moved to Upsala in the beginning of 1860. Young Svante was educated at the cathedral school of Upsala, and was fortunate in the fact that the rector of the school was a good teacher of physics. He left at the age of 17 with a good record in mathematics and physics to enter the University of Upsala, where he soon passed the candidate's examination, admitting to study for the doctorate. It seems to have been his original intention to take chemistry as his main subject under Cleve, well known for his investigations on the rare earths and on complex ammoniacal compounds. Cleve, however, was apparently an uninspiring teacher and neglected the theoretical side of chemistry. Arrhenius records that he never heard any mention from the rostrum of the periodic law, although it was already 10 years old, nor when he came to write his thesis had he any knowledge of the existence of the law of Guldberg and Waage, which was even older. In 1881 he definitely turned to physics, although the conditions for its study in Upsala were far from ideal. Thalén was at that time professor of physics there. His reverence for his master and predecessor

Ångström was so great that, beyond the apparatus for elementary students, there was little else in the department but instruments for exact measurements of wave lengths, a subject for which Arrhenius had no liking. Thalén did not encourage independent work in his laboratory, and Arrhenius was forced to look about for some other opportunity to begin physical research. He, with a fellow student, repaired in September, 1881, to Stockholm with the intention of working in the laboratory of Erik Edlund, professor of physics to the Swedish Academy. Edlund gave them a hearty welcome, and they began by assisting him in his work on electromotive forces in the spark discharge. In the spring of the following year Arrhenius started his first independent research on the decay of galvanic polarization with time, an account of which was published in the Bihang of the Swedish Academy in 1883. From this he passed to the measurement of the conducting power of electrolytic solutions.

It is of interest to inquire into the reasons which induced Arrhenius to take up this line of work. The pursuit of science, like other human activities, is not exempt from the prevalence of fashions. At the period under consideration the study of the properties of solutions was in the air. Van 't Hoff was busy tracing the analogy between dilute solutions and gases; Raoult was developing empirical methods for the determination of the molecular weights of dissolved substances; Kohlrausch had just perfected his telephone method for determining electrolytic conductivities; Ostwald was working at reaction velocities and the affinities of acids and bases in aqueous solution. Arrhenius yielded to the same influence, but curiously enough what led him to the investigation of electrolytic solutions was not directly concerned with the conducting substances themselves. He tells us that Cleve in his lectures had emphasized the impossibility of ascertaining the molecular weights of substances, such as sugar, which could not be volatilized without decomposition. Arrhenius rightly recognized that this was a great drawback, by the removal of which a considerable advance in chemistry would be rendered possible. He was unaware of Raoult's work, and thought that some light might be thrown on the molecular weight of dissolved substances by measurements of electrolytic conductivity. He knew that when some of the water of a conducting solution was replaced by more complex nonconducting substances, such as alcohol, the conductivity was lowered, and he thought it might be feasible to deduce the molecular weight of this added substance from its effect on the conductivity. He had not proceeded far with his measurements, however, when he recognized that the state of the conducting salt was the matter of primary importance.

The theory of electrolysis and electrolytic solutions was also decidedly in the air at the same period. The chains of Grotthus, the

hypothesis of Clausius on continual momentary separation of ions, Hittorf's work on migration, Helmholtz's conception of the atomic nature of electricity, the work of Kohlrausch on conductivity, were all leading up to some definite comprehensive theory which in the end was furnished by Arrhenius.

Arrhenius completed his experimental work in the spring of 1883 and wrote the theoretical part at his home in the summer of the same year. The memoir containing the results of his conductivity experiments, and the conclusions he deduced from them was submitted to the Swedish Academy of Sciences in June, 1883, and published in the following year. (Bihang, vol. 8, Nos. 13 and 14.) It is in French and is entitled "Investigations on the Galvanic Conductivity of Electrolytes. Part I. Determination of the conductivity of extremely dilute solutions by means of the depolarizer; Part II. Chemical theory of electrolytes." Arrhenius undertook the experimental investigation of dilute solutions himself, for, although Kohlrausch had made similar measurements and had quoted some numerical data, the final publication of his results was delayed till 1885. The depolarizer which Arrhenius used was an apparatus devised by Edlund in 1875, and corresponds roughly to a hand-driven rotating commutator. It is of interest to note that the conductivity cell which bears Arrhenius's name is described in this paper.

Arrhenius measured the resistance of a considerable number of salts, acids, and bases at various dilutions, sometimes as high as $v=10{,}000$. Unfortunately the actual dilutions are not given, so that it is difficult to correlate the data of Arrhenius with those of other authors. He tabulated his results so as to show in what ratio the resistance of an electrolyte is increased when the dilution is doubled. This ratio, as Kohlrausch had found earlier, is nearly equal to 2 for most salts, i. e., specific conductivity is nearly proportional to concentration. Departure from this ideal value he took as a basis for classification of the dissolved electrolytes, and showed that chemically similar substances fell into the same category when classified according to dilution ratios. A discussion of the data led Arrhenius to the conclusion that "if on dilution of a solution the conductivity does not change proportionally to the amount of electrolyte, then a chemical change has occurred on addition of the solvent." He exemplifies this by the consideration of potassium cyanide with the abnormally high dilution ratio of 2.14, which he attributes to the partial splitting of the salt into acid and base on dilution with water. The abnormal values obtained for soluble hydroxides and dilute solutions of acids he attributes to the presence of small quantities of ammonium carbonate in the solvent water.

The importance of this paper, however, does not lie in the experimental measurements or in the detailed deductions, but in the general

ideas which Arrhenius developed in the second part. Instigated and encouraged by Otto Pettersson, then professor of chemistry in Stockholm, Arrhenius greatly expanded this theoretical section, which contains the germ of the later theory of electrolytic dissociation. He bases his theoretical treatment on the hypothesis of Williamson and Clausius. How this hypothesis presented itself to a clear and critical contemporary mind, unacquainted with the work of Arrhenius, may best be gathered from the admirable report on electrolysis presented by Oliver Lodge to the British Association in 1885.

Lodge writes: "No polarization exists inside a homogeneous electrolyte; there is no chemical cling of the atoms there, but only a frictional rub. Such a fact as this, if well established, renders necessary some form of dissociation hypothesis. The form of dissociation hypothesis suggested by Clausius and Williamson is well known. It supposes that the vast majority of molecules in an electrolyte are quite insusceptible to the influence of electrodes, but that a few of them (the number being increased by complexity of composition and rise of temperature) are, by collision or otherwise, dissociated and exist in the free atomic state, each atom with its appropriate charge. These alone feel the influence of the electrodes. . . . Individual atoms, although permitted to combine as soon as they like, on this theory, are commonly thought of as existing in the dissociated state for a finite time. If there are chemical or other objections to such a view, it need not be held; all that the facts of electrolysis require is the most momentary dissolution of partnership—temporary but quite perfect freedom. . . Provided a sufficient supply of such temporary severances occurs throughout the liquid, no individual atom need remain uncombined for a thousandth of a second, so far as the phenomena of electrolysis are concerned."

Arrhenius derives from the hypothesis the notion of closed circular currents in the electrolytic solution in its normal state (i. e., when not undergoing electrolysis) which are due to the separation of the ions and their recombination with other than their original partners. This notion he uses in dealing with the equilibrium between electrolytes in aqueous solutions. But by far the most important original idea, on which he bases his further treatment, is that of the distinction of the dissolved molecules into active and inactive. He arrives at it in the following way. A solution of ammonia exhibits a feeble molecular conductivity which increases with dilution. This Arrhenius attributes to the progressive conversion of the nonelectrolytic NH_3 into the electrolytic NH_4OH as dilution is increased. He proceeds: "It has been shown that pure anhydrous hydrochloric acid is a nonconductor, that is, a nonelectrolyte. If water is added to it, it is converted into an electrolyte, naturally in a progressive

manner. It is impossible to deny the complete analogy of this phenomenon with that occurring on the dilution of ammonia or acetic acid, although it takes place much more rapidly." He sums up in the following statement: "The aqueous solution of any hydrate [i. e., acid or base] is composed in addition to the water, of two parts, one active (electrolytic), the other inactive (nonelectrolytic). These three substances (viz, water, active hydrate, and inactive hydrate) are in chemical equilibrium, so that on dilution the active part increases and the inactive part diminishes."

Arrhenius gives nowhere in this memoir a precise account of the nature of the active and inactive portions. He indicates and illustrates what they might be, but that is all; he does not define. The most important special feature of the paragraph is the statement that the active part increases on dilution. He continues: "In what respect these two parts differ remains to be elucidated. Probably the active part (as with ammonia) is a compound of the inactive part and the solvent. Or possibly inactivity may be caused by the formation of molecular complexes. Or again the difference between the active and inactive parts may be purely physical. The same statement applies to bases, and we may also speak of the inactivity of dissolved salts, in which case the notions of inactivity and complexity completely coincide."

With regard to solutions of normal salts he makes the following statements: (1) "Aqueous solutions of all electrolytes contain the dissolved electrolyte at least in part in the form of molecular complexes. (2) If the attenuation of the solution of a normal salt is continued, the complexity approaches asymptotically an inferior limit. (3) The limit to which the complexity of a normal salt at extreme dilution tends to approach is of the same degree for all normal salts. Probably this limit will not be attained before all the salts are split up into simple molecules, represented by the chemical molecular formula.

"To fix our ideas, I have introduced the notion of coefficient of activity defined as follows: The coefficient of activity of an electrolyte is the number expressing the ratio of the number of ions actually contained in the electrolyte to the number of ions it would contain if the electrolyte were completely transformed into simple electrolytic molecules.

"Before going on we shall describe more precisely the notion of coefficient of activity by the aid of the hypothesis of Williamson and Clausius. According to section 2 this coefficient is defined by the number of ions present in a solution. But to each pair of ions there corresponds an electrolytic molecule which can take part in the production of a circular current; that is to say, its ions are endowed with the movement assumed by the hypothesis. If, now,

an electrolyte is constituted in such a manner that only a certain fraction $1/n$ can at the same time take part in such a movement, it is evident that its coefficient of activity is $1/n$. It is not necessary, however, that a chemical difference should exist between the active and inactive parts. For greater clearness we choose an ammoniacal solution as example. In this solution there are two different parts, one active NH_4OH, the other inactive NH_3. If the latter is transformed into the former, the sum of the molecules of the two species is not augmented. Thus if m and n are the numbers of molecules of NH_4OH and NH_3, the first factor of the coefficient of activity will be $\frac{m}{m+n}$. Now several of the NH_4OH molecules may be associated with each other, so that the number of physical molecules of NH_4OH is p, of $(NH_4OH)_2$ q, of $(NH_4OH)_3$ r, etc., where evidently $p+2q+3r+\ldots=m$. Again of the molecules NH_4OH only a fraction $1/\lambda$ presents a simultaneous movement of ions. The corresponding numbers for $(NH_4OH)_2$ and $(NH_4OH)_3$ are $1/\mu$ and $1/\nu$. In this case the coefficient of activity of the ammonia will be equal to

$$\frac{m}{m+n}\left(\frac{p}{m\lambda}+\frac{q}{m\mu}+\frac{r}{m\nu}+\ldots\right)=\frac{1}{m+n}\left(\frac{p}{\lambda}+\frac{q}{\mu}+\frac{r}{\nu}+\ldots\right)."$$

It is interesting to compare with this coefficient of activity the "dissociation ratio" of Lodge, which is defined in the report from which I have already quoted. Lodge writes: "mn^3 is the number of grams of the electrolyzed or dissociated substance in a unit cube, and this we may write $N\mu$ where N stands for the number of monad gram-equivalents of the really electrolyzed substance per cubic centimeter and μ is its molecular weight compared with hydrogen." Considering the case of two electrolytes dissolved in the same solution, he proceeds: "there will be N_1 and N_2 to represent the amount of dissociated substance present, reckoned in gram-equivalents per cubic centimeter of solution. We come to the conclusion that we do not know the absolute velocity of any ion, and can not know it without further information regarding the dissociation ratio (that is, N_1/N' or N_2/N') of each substance present, where N' is the total number of monad gram-equivalents of the dissolved substance in a cubic centimeter of solution."

To Lodge the "dissociation ratio" is in all probability small. Arrhenius, on the other hand, contemplates the variability of the "coefficient of activity" with dilution and the likelihood of its being large in very dilute solutions.

So far the considerations are purely theoretical; now comes an important step, their union with experimental data. Kohlrausch had shown that the molecular conductivity of an electrolyte was

additively composed of two terms, one depending on the positive radical and the other on the negative radical. But in extremely dilute solutions of salts the value for negative radicals was nearly the same; therefore, according to Arrhenius, "the molecular conductivity of the active part of an acid (in dilute solution) is constant and independent of the nature of the acid," and as a corollary from this "the better the (dilute) solution of an acid conducts electricity, the greater is its active part." For want of precise data for calculating the absolute value of the coefficient of activity, Arrhenius takes it as proportional to the molecular conductivity. Thus he is enabled to compare the activities of acids amongst themselves, and of bases amongst themselves. He finds at once that the activities of acids as thus determined from their conductivities agree well with our general notions regarding their strengths, and is led to the statement that "for acids and bases galvanic activity is accompanied by chemical activity." He proceeds to discuss double decomposition in electrolytic solutions, on somewhat hypothetical grounds, and arrives at a formula (containing coefficients of activity) which he applies practically to many important reactions. If in the general equation of double decomposition

$$\underset{1-x}{AB} + \underset{n-x}{CD} \rightleftarrows \underset{p+x}{AC} + \underset{q+x}{BC},$$

are the molecular proportions at equilibrium, and α, δ, β, γ are the coefficients of activity of the various substances, then at equilibrium $(1-x)(n-x) \quad \alpha\delta = (p+x)(q+x)\beta\gamma$. If the action considered is Acid+Base$\rightleftarrows$Salt+Water, the product of the coefficients of activity on the left is, when acid and base are strong, enormously greater than the product of those on the right, and salt-formation is, therefore, practically complete. If acid or base is weak, the two products are comparable, and in consequence, entire neutralization will not take place, notable quantities of acid and base remaining free. If the activity coefficient of one of the substances (say alcohol regarded as acid) is smaller than that of water, only traces of the salt are formed. Here we find a definite treatment of salt-hydrolysis based on the following principle: "What is common to all these cases is the necessity of regarding water as an acid (or as a base) which competes with other acids (or bases) present in the equilibrium." Arrhenius states further the proposition, which requires some restriction, that "at a dilution not excessively great the quantity of salt decomposed is approximately proportional to the square root of the quantity of the solvent water."

The theory is then applied to the displacement of one acid by another, to the influence of acid salts, and to equilibrium in heterogenerous systems. The consequences of the variation of the coefficient

of activity in homogeneous and in heterogeneous systems are considered, and sections are devoted to the behavior of molten electrolytes and to thermochemistry. He deduces the following important principle: "The heat of neutralization evolved by the transformation of a base and an acid, both perfectly active, into water and a simple salt, is nothing but the heat of activation of water."

After a review of anterior theories Arrhenius summarizes his work thus: "We have first shown the probability that electrolytes can assume two different forms, one active, the other inactive, such that the active part is always, in the same external circumstances (temperature and dilution), a certain fraction of the total quantity of the electrolyte. The active part conducts electricity, and is thus in reality electrolytic; not so the inactive part. Moreover we have proved that the necessary consequences of the hypothesis of Clausius and Williamson is that there exist continuous circular currents, in which the active parts alone participate. The molecules participating in such currents are necessarily decomposed according to the scheme of double decomposition, new electrolytes being thereby formed. On this basis we have founded a chemical theory of electrolytes, which, being deduced from very probable sources, possesses also a high degree of probability. This theory leads to formulæ valid for chemical processes, formulæ very conformable to those proposed by Guldberg and Waage, which have been verified in a great number of instances. . . . As a provisional approximation we have assumed the coefficient of activity to be equal to the molecular conductivity. The numbers calculated on this hypothesis and the reactions thus foreseen, agree very well with experimental facts. . . . These propositions and these laws are taken from the most different parts of chemical science; but as the theory agrees so well with reality on these different points, it seems probable that it ought to do so also in intermediate regions. . . . The theory is completely free from any hypothesis of an affinity different from physical forces, and in this respect is preferable to all prior theories. . . . True, it may be objected that the theory is only valid for electrolytes, while previous theories have embraced all substances. Against this we remark that chemical knowledge is mainly based on the reaction of electrolytes . . . Reactions in general seem to manifest a considerable analogy to those of electrolytes, so that one could perhaps in the future enlarge the theory until it becomes, with some modification, applicable to all substances."

Nowhere does Arrhenius mention the word dissociation, although, as we have seen, the word is currently used by Lodge. The idea is, of course, there, but there is no identification of the "active part" of the electrolyte with free ions acting as separate molecules. The theory of electrolytic dissociation is as it were in solution in this memoir; it has yet to be crystallized out.

This comprehensive paper, which runs to 150 printed pages, was presented to the University of Upsala as a dissertation for the doctorate of the university. Its somewhat strange form is no doubt due to the use thus made of it. At the ends of sections and paragraphs there are numbered and italicized propositions, of widely different degrees of probability, and deduced by arguments of very different degrees of cogency. The paper then on a cursory inspection might convey an unfavorable impression if only the italicized portions were attended to. These propositions were probably the theses which were to be defended by the candidate in public debate with an opponent appointed by the university. The disputation passed off successfully and it must have been a bitter disappointment to Arrhenius when his dissertation was awarded a fourth class (*non sine laude approbatur*) and his defense a third (*cum laude approbatur*). After every allowance has been made for the novel and unusual character of the dissertation, it is difficult to see how the University of Upsala, the University of Bergman and Berzelius, should have condemned a brilliant thesis on the very subjects of affinity and electrochemistry associated with these names. For the award amounted to a condemnation; in view of it Arrhenius could not normally become a docent in the University of Upsala.

Arrhenius sent copies of his paper to Clausius, Lothar Meyer, Ostwald, and van 't Hoff. "These celebrated men," he says, "with whom the Upsala professors were not to be compared, treated me as a colleague and not as a stupid schoolboy." Ostwald was eminently friendly. He himself in his work on chemical dynamics was being drawn to the conclusion that velocities of reactions in which acids participate are connected with the electric conductivities of the acids. He writes (J. pr. Chem., 1884, 30, 93): "To test the idea I have during the past six months made preliminary experiments, which however have often been interrupted by other work. Meanwhile Svante Arrhenius, working in another range of ideas, undertook similar experiments and has published them in two memoirs, which also contain a very notable theory of chemical affinity developed from them. To the author of these memoirs, which belong to the most important ever published on the subject of affinity, there must be accorded not only priority of publication but priority of the idea."

Oliver Lodge was impressed by the paper and wrote for the Reports of the British Association in 1886 an abstract and critical analysis of it extending to 30 closely printed pages. "The paper seems to me a distinct step toward a mathematical theory of chemistry. The title affixed to it is 'The Chemical Theory of Electrolytes,' but it is a bigger thing than this: It really is an attempt at *an electrolytic theory of chemistry*."

In August, 1884, Ostwald visited Arrhenius in Upsala, and his visit had a marked effect on Arrhenius's future. Ostwald undertook to get Arrhenius appointed as a docent in Riga, and the offer no doubt led to the favorable reception of an application by Arrhenius for a similar post in physical chemistry at Upsala. The two men had, while together, projected a scheme of research on physical chemistry to be undertaken in Ostwald's laboratory in Riga, but the illness and subsequent death of Arrhenius's father kept him in Upsala. Through Edlund's influence he received in December, 1885, a valuable traveling scholarship from the Academy of Sciences which enabled him to work in continental laboratories at discretion. The next five years were Wanderjahre. In 1886 he was with Ostwald in Riga, and Kohlrausch in Würzburg, during 1887 with Boltzmann in Graz, during 1888 with van 't Hoff in Amsterdam and again with Ostwald, now in Leipzig. In 1889 and 1890 he worked in the laboratories of Ostwald and Boltzmann. When in Sweden he lectured on physical chemistry in Upsala or worked in Edlund's laboratory in Stockholm. It was during this journeyman's period of his life that the theory of electrolytic dissociation was finally developed.

His original papers left the nature of the difference between the active and the inactive portions of the electrolyte unsettled, and the absolute value of the dissociation vague. As I have said, the theory was still in solution. The nucleus which determined its crystallization came through van 't Hoff's theoretical work on osmotic pressure and his interpretation of Raoult's experimental results.

Van 't Hoff, in a memoir presented to the Swedish Academy on October 14, 1885, showed that it was possible to write for solutions an equation $PV=R'T$, analogous to the gas equation, where P, however, is the osmotic pressure instead of the gaseous pressure. The constant R' was in many cases equal to the gas constant, but in many others differed from it. Van 't Hoff then wrote the general equation for dissolved substances in the form of $PV=iRT$, where R is the gas constant and i a coefficient sometimes equal to unity, but sometimes assuming values much greater, in particular for aqueous salt solutions when the results are calculated from Raoult's experiments. For example, i is 1.98 for hydrochloric acid, 1.82 for sodium nitrate, and 1.78 for potassium chlorate. Van 't Hoff contented himself with these empirical values and made no attempt at an explanation. His paper was published in 1886, but Arrhenius did not receive a copy until March, 1887. On the 30th of that month he wrote to van 't Hoff from Würzburg: "Your paper has cleared up for me to a remarkable degree the constitution of solutions. If, for example, sodium chloride were normal in its behavior, i. e., if it consisted of simple molecules, its coefficient i would be equal to unity.

But since i is much greater than unity, the natural explanation is to say that NaCl is partially dissociated, just as we say that at high temperatures I_2 is dissociated. Now this assumption might be deemed very rash, were it not that on other grounds we are led to look upon electrolytes as partially dissociated, for we assume that they decompose into their ions. But as these ions are charged with very great quantities of electricity of opposite sign, conditions are such that we can not in all cases treat a solution of NaCl as if it simply consisted of Na and Cl. The pressure on the walls can not, however, be appreciably affected, so that in this case the solution acts as if Na and Cl were free. And when we consider which substances (according to Raoult's experiments) are abnormal, it is not the inorganic (e. g., not $HgCl_2$, CO_2, H_2S, etc.), but the electrolytic substances (i. e., substances which are conductors of the same order as salts) even when they are organic, e. g., oxalic acid. Trichloroacetic acid and sulphonic acids must show this still more clearly when they come to be investigated. Since according to the above assumption electrolytes decompose into their ions, the coefficient i must lie between unity and the number of the ions. This in reality holds good; for example, the coefficient nearly reaches 2 for NaCl, KCl, KNO_3, NaOH, etc., which have two ions; for $Ba(OH)_2$, $CaCl_2$ K_2SO_4, etc., which have three ions, it almost approaches 3, and so on. . . . From the above assumption we can even calculate the value of i from the conductivity, and this I shall probably soon carry out; till now time has failed me. What I called in my paper 'Sur la conductibilité' active molecules, are thus the same as dissociated molecules. One of the propositions which I then put forward would now be written: In all probability all electrolytes are completely dissociated at the most extreme dilution." Here we have the first appearance of the theory of electrolytic dissociation. If we can not fix its birthday, at least we can its birth month. It is clear, definite, and concise, and all Arrhenius's previous theoretical treatment can easily be translated into terms of it. Van 't Hoff accorded the new idea a favorable reception. He replied on April 7: "Your statement that the number of ions roughly keeps pace with the values of i, and that the conductivity also increases with i, agrees with most of the cases known to me." . . . He remarks that he had always thought of the dissociation into ions as being confined to an extremely small portion of the salt, but confesses that he sees no grave difficulty in assuming a greater dissociation. Arrhenius in a letter dated April 13 is pleased to learn that this is van 't Hoff's view, and states that Emil Fischer, with whom he had discussed the matter in Würzburg, although he was friendly to the idea, was of opinion that most chemists would be opposed to such far-reaching dissociation. Arrhenius continues: "It is true that Clausius had only assumed that a

minute quantity of a dissolved electrolyte is dissociated, and that all other physicists and chemists had followed him; but the only reason for this assumption, as far as I can understand, is a strong feeling of aversion to a dissociation at so low a temperature, without any actual facts against it being brought forward. In my paper on the conductivity of electrolytes I was led to the conclusion that at the most extreme dilutions all salts would consist of simple conducting molecules. But the conducting molecules are, according to the hypothesis of Clausius and Williamson, dissociated; hence at extreme dilutions all salt molecules are completely dissociated. The degree of dissociation can be simply found on this assumption by taking the ratio of the molecular conductivity of the solution in question to the molecular conductivity at the most extreme dilution." These two short excerpts give the gist of the complete theory.

Van 't Hoff and Arrhenius now made their ideas available to a wider public by publishing them in the first volume of the Zeitschrift für physikalische Chemie in the latter half of 1887. Van 't Hoff accepts Arrhenius's theory for electrolytes and adds finally Avogadro's Law to those of Boyle and Charles as being applicable to dilute solutions. Arrhenius gives the relationship between van 't Hoff's constant i and the degree of dissociation α in the form $i=1+(k-1)\alpha$ where k is the number of ions into which the molecule of the electrolyte dissociates, e. g., 2 for KCl, 3 for K_2SO_4. He compares the values of i calculated from Raoult's freezing-point data on the one hand, and from the molecular conductivity on the other, for some 80 different substances, and finds a very satisfactory accordance. In the second part of his paper he discusses the properties of electrolytes in aqueous solutions from the point of view of their additive character, which he attributes to the independence of their ions.

The theories of osmotic pressure and of electrolytic dissociation were now fairly launched, and, propelled by the driving power of Ostwald through the waters of scientific opinion, they soon attained a world-wide recognition, though often meeting very heavy weather. That their reception was so favorable is indeed somewhat surprising, for it must be remembered that in those days the marvels of X rays, of radioactivity, of wireless transmission, had not prepared the way for that loosening and abandonment of fixed physical ideas to which we are to-day accustomed, if not altogether reconciled. Their general acceptance was largely due to their comparative simplicity. They could be easily tested practically, and little mathematics was required in their development, so that experimental work, centered originally in Ostwald's laboratory but gradually spreading to others in Germany and abroad, was in the next decade assiduously carried out by a new generation of physical chemists. Their application by

Nernst (1889) to electromotive force was an advance of the first order. Arrhenius himself played a principal part in the development. Amongst his important contributions to the subject published in Ostwald's Zeitschrift may be mentioned the theory of isohydric solutions (1888), the heat of dissociation of electrolytes and the influence of temperature on the degree of dissociation (1889), the conditions of equilibrium between electrolytes (1890), the determination of electrolytic dissociation of salts from solubility experiments (1893), the hydrolysis of salts of weak acids and weak bases (1894), the alteration of the strength of weak bases by the addition of salts (1899).

At this point it may be well to refer to Arrhenius's position with regard to the problem of the abnormality of strong electrolytes, which, unlike the weak electrolytes, do not conform to Ostwald's dilution law. Naturally this puzzling exception to the theory he had put forward constantly claimed his attention. Although he did not succeed in accounting for it, he had arrived at a clear conception of the lines along which a solution might be sought, as may be seen from his book, Theories of Solution, published in 1912 from the Silliman lectures delivered at Yale in 1911. He groups the theories which might be brought forward to explain the anomaly under four headings:

1. Change of ionic friction with dilution.
2. Electric attraction of the charges of the ions.
3. Influence of foreign substances on the osmotic pressure (so-called salt-action).
4. Hydration of the ions.

The second of these, with its effect on the first and third, is now recognized as the chief cause of the abnormality. Arrhenius's original theory is sometimes spoken of as entirely obsolete. But it is well to remember that if the younger men of to-day see a little further into the nature of electrolytic solutions than Arrhenius, they do so by standing on Arrhenius's shoulders.

During these years Arrhenius also worked on other physico-chemical subjects, for example, on viscosity of pure liquids and solutions, on conduction in hot gases and flames, on diffusion in aqueous solution, on the velocity of hydrolysis of ethyl acetate and on the inversion of cane sugar in acid solutions. In a paper on the last subject (1889) Arrhenius makes another theoretical contribution of great significance. He is discussing the effect of temperature on reaction velocity which amounts at the ordinary temperature to an increase of 10 to 15 per cent for 1° rise. This is much too great to be accounted for by increase of molecular velocity or diminution of viscosity. Besides, the nature of the increase is altogether different from that exhibited in the temperature coefficient of ordinary physical properties. For

equal increments of temperature the increase is not approximately arithmetical, but geometrical. This circumstance indicates that the increase in reaction velocity with temperature is not due to change in physical properties of the reacting substances. A similar very rapid change in reaction velocity is observed when ammonium salts are added to ammonia which is saponifying ethyl acetate. Here the explanation is that the ammonium salts greatly reduce the concentration of the free hydroxide ions which really determine the reaction. May we not then surmise that in the inversion of cane sugar the amount of the really active substances is increased by temperature? The amount of hydrogen-ion, one of the active substances, is little affected by temperature. We must, therefore, assume that the other really active substance is not cane sugar, as this is not changed in amount by temperature, but another hypothetical substance, which is produced from cane sugar as fast as it is removed by inversion. Arrhenius here reverts to his old distinction between "active" and "inactive" molecules. The hypothetical substance is "active cane sugar" formed from the inactive substance. It is present at all available temperatures in very minute amount, and the quantity of it in equilibrium with the inactive cane sugar increases about 12 per cent per degree. We are therefore dealing principally with the effect of temperature on an equilibrium, namely, that between the active and the inactive substance, and can apply van 't Hoff's equilibrium equation $d \log_e k/dT = q/2T^2$, where k is the equilibrium constant and q is the heat of activation. For a small range of temperature this leads to $\log k = C - A/RT$, i. e., a straight line should be obtained on Arrhenius's assumption if we plot the logarithm of the velocity coefficient against the reciprocal of the absolute temperature, the slope of the line measuring the heat of activation. Arrhenius's equation actually applies to many homogeneous and heterogeneous reactions, and although there is much that is arbitrary in its derivation, it is in its general character quite in accordance with modern ideas.

Returning once more to his personal fortunes, we find that after 1887 he was recognized abroad as one of the chief figures of physical chemistry, but the death of Edlund in 1888 deprived him of his stoutest champion at home, and greatly reduced his chances of obtaining suitable academic employment in Sweden. Abortive negotiations to establish him in a chair of physics at Utrecht and of chemistry at Graz were succeeded by a definite call to the chair of chemistry at Giessen in 1891. Arrhenius, however, notwithstanding the *invidia inter suos* to which he had been subjected, was intensely patriotic and declined the offer on the chance of being appointed chief of the laboratory of physics in the Högskola (University College) at Stockholm, a post which at this time had become vacant. Arrhenius was

successful in his candidature and obtained this lectureship, which was in 1895 converted into a professorship, although once more against formidable opposition, only overcome by the strong backing of German physicists. This chair Arrhenius held till 1905. During the years 1896–1902 he was rector of the Högskola, and through his personality did much to stabilize and develop the struggling institution notwithstanding that he had no fondness for administrative tasks. Although his laboratory was small and poorly equipped, the name of Arrhenius was sufficient to attract foreign workers, among whom may be mentioned Abegg, Bredig, Cohen, and Euler, who afterwards succeeded him in the chair. Foreign distinctions also began to come his way. He was elected an honorary fellow of this society in 1898, and was awarded the Davy Medal of the Royal Society in 1902. At last he received recognition, and that of the most handsome description, from his own countrymen by the award of the Nobel prize for chemistry in 1903.

His interest had meanwhile been diverted from the study of solutions to other fields of science, at first to cosmic and meteorological problems.

One of his very early papers (1883) dealt with an observation of globe lightning near Upsala, and his work on conducting gases had led him to study electrical phenomena in the earth's atmosphere. With his friend the meteorologist, Nils Ekholm, he investigated the influence of the moon on the electric state of the atmosphere, on the aurora and on thunder storms. In a long memoir (1896) he attempted to account for the onset and passing of glacial periods by the variation in the amount of carbon dioxide in the atmosphere. This gas exerts a selective absorption, allowing the solar radiation freely to pass inwards, but to a great extent stopping the lower-temperature radiation from the earth outwards. Arrhenius calculated that from this greenhouse effect the temperature in the Arctic regions might rise 8° C. if the carbon dioxide content of the atmosphere increased to somewhat more than double its present value, and that in order to get the temperature of an ice age between the fortieth and fiftieth parallels, the value would have to sink to about half. The variation in the carbonic acid content he attributed chiefly to variation in volcanic activity. The problem of the ice ages is still a vexed question amongst geologists, but Arrhenius made a notable contribution to its discussion.

Another important paper on a geological subject was a theory of vulcanicity based on physico-chemical principles (1900). According to it the sea floor acts as a kind of semipermeable membrane, permitting water molecules to pass but not silicate molecules. Water at no very great distance under the surface of the crust would be at a temperature above its critical point, and therefore a gas, and would

be absorbed by the fluid magma under the great pressures existing. But by extrapolation from known data it may be shown that, although at room temperature water is a much weaker acid than silicic acid, yet at high temperatures the reverse is the case, water at 1,000° being probably 80 times stronger than silicic acid. In the magma, then, water will attack and decompose silicates, and thus be potentially stored up in the form of acid and base. When the magma on rising is cooled, the reverse process takes place; water is liberated and at a certain height will overcome the pressure of the column above it, eject the superincumbent fluid, and cause a volcanic eruption. A volcano thus acts in much the same way as a geyser. The theory aims at explaining the proximate cause of eruptions, and has met with wide acceptance.

In 1898 Arrhenius wrote a remarkable paper on the action of cosmic influences on physiological processes, and in 1903 he surprised his chemical friends by publishing his "Lehrbuch der kosmischen Physik," a work of extraordinary learning and scholarship. In it he passes under review an extensive collection of observational material and deals with it according to his own methods. The most striking novelty of treatment is the use he makes of radiation pressure, the existence of which had been predicted by Clerk Maxwell. It was applied by Arrhenius to various cosmic phenomena even before its experimental confirmation in the laboratory by Nichols and Hull and by Lebedev. Arrhenius calculated that at the surface of the sun the repulsive force of the radiation would balance the sun's gravitational attraction on black particles of diameter about 1.5μ, and specific gravity 1, and that smaller particles than these would be repelled. Schwarzschild made some necessary corrections and showed that the maximum repulsion would be for completely reflecting particles (sp. gr. 1) if their diameter was about 0.16μ, and it would then be 10 times the gravitational attraction. From the sun then we might expect streams of such minute particles to be shot out in all directions. Many of these particles would be electrically charged from the ionisation existing in the sun's gaseous atmosphere. Arrhenius shows how the phenomena of the solar corona, comets, the aurora, and the zodiacal light may be caused or influenced by these particles.

With the beginning of the present century Arrhenius's thoughts took a new turn. Thorvald Madsen had succeeded in arousing his interest in the application of physico-chemical ideas to serum therapy. In 1900 and 1901 he did some experimental work with Madsen in Copenhagen, and later in Ehrlich's laboratory in Frankfort. In 1902 he published jointly with Madsen a memoir on the occasion of the opening of the Danish State Serum Institute, of which Madsen had been appointed director. It was entitled "Physi-

cal Chemistry Applied to Toxins and Antitoxins." Madsen was responsible for the experimental methods, Arrhenius for the theoretical treatment. They maintained that the toxin-antitoxin combination (held by Ehrlich to be a firm chemical union) was in reality reversible, and governed by the ordinary mass-action law. The immunological phenomenon of antitoxin action was likened to the interaction of a weak acid and a weak base, such as boric acid and ammonia, which only partly neutralize each other. The work constitutes a classical study among the early researches into the underlying nature of immunity phenomena, and contributed to laying the foundation of "immunochemistry," a term first applied by Arrhenius himself to a branch of biological research in which reactions of markedly specific character occur between biological principles of unknown chemical nature. Arrhenius pursued this type of research for a decade, and published two books dealing with it, Immunochemistry in 1908, and Quantitative Laws in Biological Chemistry in 1915.

In the year 1905 Arrhenius happened to be in Berlin and was asked by the university adviser of the Prussian Ministry of Education if he would be inclined to accept a position in the Prussian Acadamy, similar to that held by van 't Hoff. This was a very tempting proposal, but Arrhenius, with his usual patriotism, requested time to consider it, and asked and was granted permission to speak of it to the Minister of Education in Sweden. It had been the intention of the Academy of Sciences to found a Nobel institute for chemistry and one for physics, but the wish having been expressed by King Oscar II that Arrhenius should not be allowed to leave Sweden, the academy resolved to found forthwith, instead of the two proposed institutes, a Nobel institute for physical chemistry, and of this new foundation Arrhenius was appointed director. It was housed at first in temporary quarters in Stockholm, but at Experimentalfältet, a pretty park in the neighborhood of the town, a small laboratory was erected with an official residence attached. The laboratory was inaugurated in 1909. Here, with an assistant and a few research workers as guests, Arrhenius could work and write under ideal conditions on such problems of physical chemistry, physiological chemistry, immunochemistry, meteorology, and cosmic physics as might please him.

The stormy period of Arrhenius's career was now definitely over, and from the time of his appointment to the Nobel Institute life went very smoothly with him. From being a scientific outcast in Sweden he became a scientific oracle, known and respected by all classes of the people.

He himself did little practical work in the new laboratory, but stimulated and encouraged others. One of his chief pleasures was

to attend conferences in all countries for the purpose of meeting his scientific colleagues and discussing with them their special problems. He often visited England and was elected a foreign member of the Royal Society in 1911. In the same year he lectured in America and was presented with the Willard Gibbs Medal of the American Society. In 1914 he gave the Faraday lecture to our own society, and the Tyndall lecture to the Royal Institution.

Arrhenius liked to acquire knowledge at first hand, and visited many laboratories for this purpose. He spent, for example, three weeks in Rutherford's laboratory in Manchester, working at a practical course in radioactivity under Geiger. At the end of a week he had started a research on the solubility of active deposits, and was with difficulty dragged away from his electroscope to witness some of Jacques Loeb's starfish experiments at the marine biological station.

He devoted a large part of the later years of his life to popularizing science. A firm believer in progress through enlightenment, he sought to bring a knowledge of scientific fact and method before the general public. His clear and easy style made his books attractive, though the matters dealt with were often in themselves difficult. The first of these books, Världarnas Utveckling (Worlds in the Making), which treats in a popular manner some of the subjects of his Kosmische Physik, had an immediate and world-wide success, being translated into all the important European languages.

Happy in his work and happy in his family life, Arrhenius during his later years radiated contentment. He was twice married—in 1894 to Sofia Rudbeck, and in 1905 to Maria Johansson. By the first marriage he had one son, Olov Vilhelm Arrhenius, who is known for his work in soil science and agricultural botany, and by the second a son and two daughters.

His health remained good until the autumn of 1925, and although he recovered in a remarkable way from the first seizure, he retired from the directorship of the Nobel Institute in February, 1927, when he was granted a full pension and the right to remain in the official residence. On October 2, 1927, he died after a week's illness, and was buried in Upsala on the 8th of that month after a solemn service in Stockholm on the previous day.

Arrhenius was of the old breed of natural philosophers, a true polyhistor, devoted to science at large. Being endowed with a memory both tenacious and accurate, he had a marvelous command of scientific fact. He was, however, no unimaginative empiric; his synthetic fancy played over the vast store of knowledge and sought relations between apparently isolated regions. In consequence, his original ideas were concerned with borderland sciences—physical chemistry, cosmic physics, geophysics, immunochemistry.

The conjunction in him of two special faculties explains the character of much of his work—his aptitude for scientific speculation, and an extraordinary facility in dealing with figures. He loved statistics and it is recorded of him that as a very small boy he delighted to sit beside his father and help him in casting his laborious accounts. Arrhenius might begin a new line of work by the consideration of tables of numerical data collected by himself or others. He would frame a formula to fit them—an exercise at which he was uncannily expert—and then evolve a physical hypothesis to account for the formula. Or he might start with a bold speculation as to how two entities were related, formulate this relation, and check the formula by means of data of observation or experiment. There was constant interplay between the speculative and the quantitative sides of his mind. I recollect that one day in the laboratory at Leipzig, after a long spell of very arduous experimental work, he downed tools, saying, "I have worked enough; now I must think," and did not reappear in the laboratory for a fortnight. Extreme experimental accuracy he never aimed at, considering it rather a disadvantage in the search for a general law, and he used to boast that he had never performed an exact experiment in his life. But this statement must be taken with a grain of salt. I know that his work at Leipzig was certainly more accurate than that of most of his fellow workers in the laboratory, although carried out with the simplest possible apparatus.

Arrhenius had nothing academic about him save learning. In person he was stoutly built, blond, blue-eyed, and rubicund, a true son of the Swedish countryside. His nature was frank, generous, and expansive. He was full of robust vitality and primitive force. He had hearty likes and dislikes, and beneath his inborn geniality and good humor was a latent combativeness, easily aroused in the cause of truth and freedom.

He was not politically active, but he was fond of discussing the large questions of world politics. He spoke very bitterly of Norway when she broke the union with Sweden, but later admitted that the separation had been best for both countries, and expressed to me the hope that Britain would give Ireland similar complete freedom. The World War he regarded as essentially a struggle between Germany and Britain, and although his greatest scientific friends belonged to the Central Powers, his sympathy was definitely with the Allies.

A word may be said about Arrhenius as a linguist. He held that to speak a foreign language what one wanted was, not so much knowledge as courage. Being liberally endowed with this latter quality he spoke and wrote many languages with ease and confidence, if not with accuracy. Indeed he considered it a waste of time

to acquire the niceties of a language, and was of opinion that there should be a universal language—he suggested a simplified English. Any shortcomings of accent or idiom in his own English were amply compensated by a Shakespearean richness of vocabulary, which gave extraordinary pith to many of his sayings.

He paid little regard to literature or art, but keenly appreciated natural beauty, especially the gladdening phenomena of spring. His life-long interest in the lovely northern dancers and in comets that "brandish their crystal tresses in the sky" had most likely an æsthetic as well as a scientific basis.

Sweden can boast of many eminent names in science, of which two are by common consent of the first magnitude—Linnæus and Berzelius. Since the death of Berzelius she has had no name to rank with these save the name we commemorate to-day—Arrhenius. Yet withal Svante Arrhenius was so simple, so genuine, so human a personality that those who had the privilege of his intimacy always forgot the great scientific master in the genial companion and the kindly, lovable friend.

THEODORE WILLIAM RICHARDS (1868-1928)

THEODORE WILLIAM RICHARDS[1]

By Gregory P. Baxter

[With one plate]

On April 2, 1928, the scientific world was shocked by news of the death, after a short illness, of Theodore William Richards, Erving professor of chemistry in Harvard University. Until within three weeks of his death he performed his usual duties, but from that time he failed rapidly. His father, William Troost Richards, noted marine artist, as well as his mother, Anna Matock Richards, were natives of Pennsylvania, and it was in Germantown, Pa., on January 30, 1868, immediately after the return of his parents from a European trip, that Theodore Richards, the fifth child, was born.

Childhood was passed under stimulating surroundings. His father was a very wise and far-seeing man as well as an artist; his Quaker mother an author of both prose and poetry; his three brothers and two sisters as well as he possessed a rich intellectual inheritance; artists, authors, and scientists were intimate family friends at his father's Germantown and Newport homes; two years were spent in Europe, largely in England. By a wise decision on the part of his parents Richards' early education up to the time of entering college was obtained at home from his mother. His quick intelligence was impatient of delay, and to conform to normal educational speed would unquestionably have been irksome if not disastrous. Although he was prepared to enter Haverford College at the age of 13½, because of his youth entrance to college was postponed for one year. But in the meantime he undertook the studies of the freshman year at home, still under the tutelage of his mother, and joined the sophomore class at Haverford in the fall of 1882.

Scientific interest showed itself early. As a boy he lived through two "boughten" sets of chemicals unharmed, and while still at home was taken into the chemical laboratory of the University of Pennsylvania Medical School by Doctor Marshall and given special instruction in qualitative analysis. In Haverford College, under Prof. Lyman B. Hall, he laid a firm foundation for his future work in chemistry, although his interest at that time was divided between

[1] Reprinted by permission from Science, Vol. LXVIII, No. 1763, Oct. 12, 1928.

chemistry and astronomy. Possibly only the accident of defective eyesight deterred him from selecting the latter field for his life work, but it is probable that acquaintance with Prof. Josiah P. Cooke, of Harvard, who was a summer neighbor at Newport, exerted a strong influence on his decision. At any rate, after graduating with high honors at Haverford in 1885 he entered Harvard College as a senior specializing in chemistry. In order to do this, it was necessary for him to pass the examination in Greek for entrance to Harvard. Again, with the help of his mother, he succeeded in preparing for the examination in six weeks of study during the summer. As a senior at Harvard his time was devoted to completing under Professors Cooke, Charles L. Jackson, and Henry B. Hill the fundamental preparation necessary for advanced work in chemistry. On commencement, 1886, the bachelor of arts degree was awarded with highest honors in chemistry, summa cum laude.

At Harvard the influence of Cooke upon Richards was immediately apparent. Cook's interests were largely in the field nowadays labeled physical chemistry, partly by inclination, partly, perhaps, through association with the French physicist Regnault, under whom he had worked some years earlier as a student. One of Cooke's earliest publications concerned the numerical relations between the atomic weights of similar elements. But this investigation had made clear to Cooke the necessity for more accurate determinations of the atomic weights and he had undertaken the experimental revision of some of these constants. Under Cooke, Richards as a graduate student at Harvard carried through a redetermination of the relative atomic weights of hydrogen and oxygen, which holds its place to-day as one of the outstanding determinations of this important ratio. No problem of the sort could have presented more difficulties than did this one, and in this investigation appear all the qualities which later were so vital for the work which Richards was to do. An infinite capacity for taking pains, an uncompromising attitude toward the possibilities of hidden errors, a determination to be certain that no precaution had been overlooked, an extraordinary persistence in the patient repetition of exacting and laborious experiments were combined with unusual manual dexterity and ingenuity, the exercise of which must have given great satisfaction to the possessor. One can not but feel that although these qualities would unquestionably have brought success wherever they were directed, chance favored him in presenting at the outset a field in which his talents could be so profitably employed.

After receiving the doctor's degree in 1888 at the age of 20, Richards spent the following year as the holder of a traveling fellowship in study at German universities under Jannasch, Victor Meyer, Hempel, and others. His plan of devoting half of the year abroad

to intensive study in one institution, followed by a half year of peripatetic study, was one which he always advocated afterwards to students with a similar opportunity as offering on the whole the greatest good for the time available.

In the fall of 1889 he returned to Harvard as assistant in quantitative analysis, never again to break his connection with the university as a teacher. Promotion to an instructorship came in 1891 and to an assistant professorship in 1894. In 1901 he received the very unusual honor, at that time, of a call to a chair in a European university. The University of Göttingen invited Richards to accept a full professorship in chemistry, with only nominal teaching duties beyond the conducting of investigation. To a man impatient to make rapid progress in research, but working with a heavy teaching load, in a laboratory far from ideal, such an opportunity was tempting in the extreme. Fortunately Harvard appreciated the value of the promising young scientist and rose to the occasion with the offer of a full professorship and an agreement of a drastic reduction in the amount of teaching and administrative duties expected. Upon the retirement of Professor Jackson in 1912, Richards was appointed to the Erving professorship, founded in 1792, the oldest endowed professorship in chemistry in Harvard University.

Immediately after his return from Europe to Harvard in 1889 Richards reentered the field of chemical investigation in which he had already made a beginning, and which was to occupy a large part of his attention during the remainder of his life. Always convinced that only through a precise knowledge of the properties of matter was progress in chemical science to be made, he was fond of making the following quotation from Plato: "If from any art you take away that which concerns weighing, measuring, and arithmetic, how little is left of that art!" Furthermore, at that time the atomic weights and the periodic law seemed to him to offer more promise of contributing to the understanding of the laws of the universe than any other field of chemistry. In a paper printed in 1910 he says:

> But some may contend that the very exact determination of these quantities is after all an abstract and academic question, not of great practical significance. How will this remote philosophical knowledge yield any practical use? Who can tell? Faraday had no conception of the electric locomotive or the power plants of Niagara when he performed those crucial experiments with magnets and wires that laid the basis for the modern dynamo. When mankind discovers the fundamental laws underlying any set of phenomena, these phenomena come in much larger measure than before under his control and are applicable for his service. Until we understand the laws all depends upon chance. Hence, merely from the practical point of view of the progress of humanity, the exact understanding of the laws of nature is one of the most important of all the problems presented to man; and the unknown laws underlying the nature of the elements are obviously among the most fundamental of these laws of nature. In brief, that is the reason why more than 20 years ago

the systematic study of the atomic weights was begun at Harvard University by the author.

Observations during the work upon hydrogen under Cooke led him to suspect inaccuracy in the atomic weight of copper, and this subject engaged his energies both before and after his trip to Europe. The thoroughness with which this work was done was characteristic. In order to avoid the danger that a single method might be affected by some constant undetected error, not one but several methods were employed, after each method had been scrutinized with the greatest care. The copper was subjected to the most elaborate purification, and in order to make sure that copper always possesses the same atomic weight, no matter where it occurs in the earth's crust, specimens from widely different sources were examined. As a result of this work a new value for the atomic weight of copper was obtained which has shown no evidence of requiring even slight alteration up to the present. The research on copper was followed by similar investigations upon the atomic weights of other common elements, barium, strontium, and zinc being those next attacked. Up to the time of his death, either with his own hands or with the aid of assistants, Richards redetermined the atomic weights of 24 of the 84 elements which have been isolated in quantity.

Greater academic responsibilities, as well as an increasing number of research students, early made it out of the question for him to carry on a large amount of experimental work with his own hands, so that in much of his later investigations the laboratory manipulation was performed by assistants. The necessity for this is obvious if it is remembered that an expert might spend all his time for a year or even several years in the determination of a single atomic weight.

In the course of this work many new analytical processes were devised and old ones perfected. New methods of purification were invented and new criteria of purity established. Especially Richards appreciated the extreme difficulty, not previously recognized, of freeing substances, otherwise pure, from the ever-present water, and devised the well-known "bottling apparatus" for inclosing and preserving the carefully dried substances in a dry atmosphere preparatory to weighing. The "nephelometer" for comparing and measuring traces of solids suspended in liquids was another product of necessity. The importance of taking into account the solubility of "insoluble" substances was pointed out and the great danger of the contamination of precipitates through inclusion and occlusion was emphasized. All these perfections of analytical methods have been of subsequent service not only in the determination of atomic weights but in analytical chemistry in general.

At the outset of Richards's career the work of the Belgian chemist Stas upon atomic weights was universally accepted as representing

the nearest approach to perfection which had ever been attained. Constant study of Stas's work enabled Richards to improve upon the former's methods in many ways, without, however, at first arousing any suspicion of inaccuracy in Stas's experiments. For the most part the work of the two had not overlapped, and there had been insufficient basis for comparison. But ultimately discrepancies began to appear, and in 1904 a redetermination of the atomic weights of sodium and chlorine was completed which showed conclusively that in the case of these elements Stas's work was vitiated by appreciable errors not difficult to trace. Subsequent developments in Richards's laboratory have shown that Stas, although years ahead of his time, was in error by important amounts in nearly all his work. A new era in analytical accuracy was thus inaugurated by Richards and the students who worked under him.

Later, in 1913, when the question was raised of probable differences between the atomic weight of common lead and those of isotopes of radioactive origin, it was to Richards's laboratory that Dr. Max Lembert was sent from Karlsruhe with specimens of uranium lead in order to settle this important question. The first direct evidence of the lower atomic weight of uranium lead resulted from their investigation.

Richards is most widely known for his work on atomic weights. It was this work which brought him membership in the American Academy of Arts and Sciences at the age of 23 and in the National Academy of Sciences at the age of 31, as well as the Nobel prize at 47. From 1899 to 1902 he was a member of the International Committee on Atomic Weights and since 1919 of the International Committee on Elements and the subcommittee on atomic weights. He never lost interest in this field, and there has seldom been a time when the investigation of one or more atomic weights has not been under way in his laboratory. Furthermore, the experience in exact methods thus obtained was invaluable in the quantitative development of other fields in which he ultimately became interested.

While Richards's original contributions in fields of physical chemistry other than that of atomic weights are too numerous and varied to be described in detail here, certain phases of the work should be emphasized because they represent steps in advance as important from the standpoint of precision as his determinations of atomic weights. His first published paper was concerned with a minor problem in thermochemistry, the constant heat of precipitation of silver chloride. Later, recognizing that this portion of the field of thermodynamics was of fundamental importance, he devoted much time and energy to its practical and theoretical aspects. From a practical point of view he endeavored very successfully to increase the accu-

racy of thermochemical measurements. This was largely effected by means of the "adiabatic calorimeter," in which the calorimeter is surrounded with a larger vessel the temperature of which is caused to follow closely that of the calorimeter during the experiment. This ingenious device, original with Richards, although the suggestion had been made earlier by Person, enables the troublesome corrections for loss of heat to or gain of heat from the surroundings, and for lag of the thermometer, to be avoided. With this apparatus he made accurate measurements of the specific heats of solids at low temperatures, the specific heats of liquids, the heats of evaporation of liquids, the heats of solution of metals in acids, the heats of combustion of organic substances, and heats of neutralization.

From a theoretical point of view he early recognized the importance of alteration in the heat capacity of a system undergoing a chemical change, and several years before the publication of the third law of thermodynamics by Nernst he pointed out the close relation between this alteration and the difference between the "total energy change" and the "free energy change" during a chemical reaction, together with the high probability that this difference gradually disappears as the absolute zero of temperature is approached.

Richards was the first to make exact determinations of the transition temperatures of hydrated salts, and to suggest their advantages as fixed points in thermometry, since extreme alterations in the temperature of the thermometer may be avoided by their use.

In electrochemistry Richards made very detailed investigations of the copper and silver coulometers and showed that Faraday's law holds with great exactness both in aqueous solution and with fused salts. The study of single potential differences, especially that of iron under varying conditions, and of the electromotive forces between amalgams of different concentrations with their theoretical implications engaged his attention at various times.

For more than 25 years Richards's activity was very largely concerned with the experimental and theoretical consideration of the apparent volumes and compressibilities of the chemical elements. Experimentally this involved the devising and using of new forms of apparatus for the very exact measurement of the compressibilities of the elements and their compounds, as well as the related properties, surface tension, and heat of evaporation. He first developed clearly the close parallelism and periodicity of atomic volume and compressibility, and the relations between compressibility and increase or decrease in volume during a chemical change on the one hand and chemical affinity and cohesion on the other, and called attention to the extreme improbability of constant atomic volume of an element in different states of chemical combination. In this work he was led to very definite and interesting ideas as to the effect of

chemical affinity and cohesion upon the configuration of an atom and their relation to such properties of material as surface tension, vapor pressure, and heat of evaporation. In recent years he was engaged in the derivation of a mathematical expression for computing from the compressibilities and other data the actual internal pressures which hold matter together, and had obtained extremely interesting and striking results. The importance of the facts and generalizations in this field brought forward by Richards is beyond question, and while he had made little effort to correlate them with the most recent ideas of the constitution of matter there seemed to be no conflict in the two points of view.

Besides the foregoing topics many problems in chemical equilibrium and in analytical chemistry are included among the subjects considered in the nearly 300 scientific papers published during his 40 years of activity as an investigator.

While it is always difficult to evaluate the ultimate importance of contemporaneous advances in any field, I believe that everyone will agree that Richard's contributions to the technique of precise physico-chemical investigation will always stand out prominently in the history of this period of American chemistry. In time further advances will surely come, just as Stas and Richards himself were able to make vast improvements on the existing situations. Doubtless Richards could have carried the refinement of his work to a greater extreme if the needs of the time had required it. Certainly up to the present no one else has done so.

To me one of the most striking features of his work is the uniform care with which every aspect of an investigation was considered and every contingency foreseen. It was never his way to close up the bunghole and leave the spigot open. This was due in part to never losing sight of the fact that measurements, no matter how accurate, are of no permanent value unless the materials being measured are of undoubted purity and definiteness, and the process free from defects, but in part it was undoubtedly due to an excessively cautious temperament, which probably saved him from making false steps. To one familiar with the experimental methods of his laboratory it is interesting to see the widespread adoption of these methods by other laboratories in the fields where they are applicable.

It was Richards's belief that his career as a scientific investigator brooked no interference outside the inevitable calls of the university and his home. For this reason he never found time for the writing of books. Aside from several monographs printed by the Carnegie Institution and a collection of papers printed in Germany, his writings were confined to scientific papers, addresses, and biographies. For the same reason he was always unwilling to undertake technical or consulting work. And especially during recent years he was sel-

dom seen at scientific meetings because he found the necessary journeys and the attendant excitement too much of a drain on his store of nervous energy.

It was not only as an investigator that Richards's influence was very great. His teaching experience began while he was a graduate student, when he served as a laboratory teaching assistant. In the summer of 1890 he taught elementary chemistry in the Harvard Summer School and devised for the purpose a new inductive method of presenting the subject. This method was later adopted by Harvard University as the approved method of preparing for the entrance examination in chemistry and exerted a profound influence on the teaching of chemistry in secondary schools, especially in New England. He taught quantitative analysis in Harvard College from 1889 to 1902. In the advanced course the lectures were largely devoted to the application of the most recent advances in physical chemistry to analytical chemistry, an unusual thing at that time. In 1895 the death of Professor Cooke left the course in physical chemistry without a permanent instructor. Richards spent the late spring and summer in Germany studying under Ostwald and Nernst, and in the following year gave for the first time the advanced course in physical chemistry with which he was associated during the remainder of his life. This course dealt especially with the underlying causes of phenomena without involving the student hopelessly in mathematical details. Since the members of the course were largely graduate students, in order to keep in touch with the undergraduates Richards gave the whole or a part of a course in elementary physical chemistry presented from a historical standpoint, a side of the subject which he considered of very great importance. Since he possessed to a high degree the faculty of understanding the difficulties of others and of presenting a subject in a simple and illuminating way, these courses were always especially valued by both the students and his colleagues. Fortunate as are those who have had the privilege of hearing his lectures, even more so are those who were his collaborators in research. His daily visits to the laboratories of his research students invariably brought encouragement and inspiration, either through his enthusiasm or by crucial suggestions. Satisfied with nothing but the best, he aroused the students to new levels of carefulness and thoroughness, at the same time insisting on a judicial sense of proportion as to the essential and the nonessential. What wonder therefore that not only American students came to Cambridge for his instruction but also selected pupils from European institutions, who were sent to his laboratory for special training in exact measurements, a reversal of the old order! Of these, Gilbert N. Lewis in America and Otto Hönigschmid in Germany are best known. In 1907 he spent the second half year at the University of Berlin as

exchange professor, the only instruction which he ever gave away from Cambridge.

Although theoretically exempt from administrative duties after his call to Göttingen, in time of need he did not hesitate to step into the breach as chairman of the division of chemistry from 1903 to 1911, and in this capacity served the division with the most conscientious attention to detail and with far vision for the future.

All of Richards's early experimental work was performed under most trying conditions in an old and inadequate structure. At no time could he feel sure that noxious gases produced in some remote part of the building would not find their way into his laboratory to ruin the products of days or weeks of labor. On one occasion the ceiling of his laboratory was brought down about his ears by a miniature flood in the room overhead. At this period constant watchfulness to avoid untoward accidents of this sort was as important for his work as analytical skill. That he was able to carry on his work at all under these conditions is a splendid example of the superiority of man over circumstances. Visions of a new laboratory, with freedom from dirt and fumes as well as vibrations, were in his mind almost from the outset. At times the fulfillment of his hopes seemed so imminent that he prepared detailed plans for a research laboratory for exact work, only to be met with disappointment. It was not until 1912 that he was enabled to realize his ambitions in this direction. Largely through the generosity and interest of Dr. Morris Loeb funds for a research laboratory of physical chemistry were secured. Richards immediately set about the perfecting of the designs of an ideal laboratory with the same care, thoroughness, and imagination with which he undertook a scientific investigation. In equipment, convenience, freedom from fumes and dirt, and from rapid temperature changes the Wolcott Gibbs Memorial Laboratory has probably never been equaled.

The list of honors which he received was a most imposing one. Between 1905 and 1923 he was the recipient of honorary degrees of D. Sc. from Yale, Harvard, Cambridge (England), Oxford, Manchester, and Princeton; of LL. D. from Haverford, Pittsburgh, and Pennsylvania; of Ph. D. from Prague and Christiania; of Chem. D. from Clark, and even of M. D. from Berlin. The Davy medal of the Royal Society (London) was received in 1910. On the occasion of the award to him of the Faraday medal of the Chemical Society (London) in 1911 he delivered an address on The Fundamental Properties of the Elements. In 1912 the award of the Gibbs medal of the Chicago section of the American Chemical Society was the occasion of an address on Atomic Weights. The Franklin medal was given to him by the Franklin Institute in 1916. The second American scientist and the only American chemist to receive the Nobel

prize, that of 1914 awarded in 1915, he was deterred by war conditions from visiting Sweden at that time, and when later, in 1922, he went to Europe with the intention of delivering the Nobel address, the critical illness of his older son, who accompanied him, again interfered with his visit to Scandinavia. At this time he was given the LeBlanc and Lavoisier medals of the French Chemical Society. In 1925 he was made an officer of the French Legion of Honor.

Besides holding membership in various American scientific societies, he was a vice president of the Eighth International Congress of Applied Chemistry in 1912, president of the American Chemical Society in 1914, of the American Association for the Advancement of Science in 1917, of the American Academy of Arts and Sciences in 1919–1921, and was to serve as the honorary chairman of the September, 1928, meeting of the American Chemical Society. Honorary memberships in the Royal Institution of Great Britain, the Chemists' Club of New York, the Harvey Society, the Franklin Institute, the Royal Irish Society, the Royal Society of Edinburgh, and the French Chemical Society were received in that order. He was foreign member of the Swedish Academy of Sciences, the Royal Italian Academy (dei Lincei), the Royal Society of London and the Danish Royal Academy, and corresponding member of the Prussian Academy of Sciences, the Brooklyn Institute of Arts and Sciences, the Royal Academy of Sciences of Bologna, and the French Academy of Sciences. In 1908 he was appointed lecturer in the Lowell Institute in Boston and gave a series of lectures on The Atomic Theory. He was a member of the National Research Council from the time of its organization throughout the war, and during the war was consulting chemist under the War Department. Since 1902 he had been a research associate of the Carnegie Institution.

It is seldom that an endowed professorship is named for a person then living, but in 1925 Richards's friends were delighted by the announcement that Mr. Thomas W. Lamont, in memory of his brother, Hammond W. Lamont, had established at Harvard the Theodore William Richards professorship of chemistry.

Genial and social in his inclinations and with a whimsical sense of humor, he was a welcome addition to any gathering, for his interests included practically every form of human activity, especially art and music. His artistic inheritance might well have been developed as his vocation. As a youngster he planned to follow in his father's footsteps and always obtained enjoyment from exercising his ability to sketch and paint. One of the most interesting sights in the Gibbs Laboratory was a marine picture which was the joint production of father and son. He was particularly warm-hearted and generous toward his friends. No trouble was too great for him to take in their

interests, and no pleasure greater than his at their success. To me the 35 years of close association with Richards as his pupil, colleague, and friend will always be one of the greatest privileges of my life.

Although never an athlete in a strict sense, he was fond of various outdoor sports. He was especially interested in yachting, and for many years as a young man spent a portion of his summers on his cruising yawl. At one time he was a good tennis player, and he was one of the earlier devotees of golf in America. The latter pastime he never gave up.

In 1896 Richards was married to Miss Miriam Stuart Thayer, daughter of Prof. Joseph Henry Thayer, of the Harvard Divinity School. Of their three children, Grace Thayer is the wife of Prof. James B. Conant, of Harvard; William Theodore has inherited his father's scientific tastes and is assistant professor of chemistry at Princeton University, while Greenough Thayer is a student of architecture.

His domestic inclinations were very strong and his wife's appreciation of his work was extraordinarily sympathetic. It would be hard to decide which was greatest, his devotion to his family, to Harvard University, or to science, but it is certain that no one could have been more forgetful of self in the interest of any of them. His creed with relation to the last one of the three has been left in his own words and is typical of his desire to give faithful service:

> First and foremost I should emphasize the overwhelming importance of perfect sincerity and truth; one must purge oneself of the very human tendency to look only at the favorable aspects of his work, and be ever on the lookout for self-deception (which may be quite unintentional). Next, one should never be content with a conventional experimental method or scientific point of view; one should be open-minded as to the possibility that the procedure or hypothesis may be incomplete. Each step should be questioned, and each possibility of improvement realized. And then, patience, patience! Only by unremitting, persistent labor can a lasting outcome be reached.

INDEX

A

B

C

D

E

O

P

R

○